HEADWATERS CONTROL AND USE

UPSTREAM ENGINEERING CONFERENCE · 1936

Headwaters control and use

Air-type view of a model of correct farm practices and other headwater controls, representing a typical area of 550 acres in a North Central State, prepared for the U. S. Soil Conservation Service. The map on the outside front cover is a simulation of the blue print from which this model was constructed.

HEADWATERS CONTROL AND USE

A SUMMARY OF FUNDAMENTAL PRINCIPLES AND THEIR APPLICATION IN THE CONSERVATION AND UTILIZATION OF WATERS AND SOILS THROUGHOUT HEADWATER AREAS

PAPERS PRESENTED AT THE
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PART I

WATER BEHAVIOR AND LAND-WATER RELATIONSHIPS

CHAPTER I

BASIC PRINCIPLES OF WATER BEHAVIOR

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A RATIONAL exposition of the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground, is the science of hydrology. Although man for thousands of years has been more directly affected in his life and developing civilization by water than by any other manifestation of nature, and although there is an enormous literature on the subject, it is not yet possible to call hydrology a science in the sense that, given definite factual premises, such as rainfall, one cannot accurately deduce the resulting disposition of the water in a scientific and mathematical manner.[1] This is due to two chief factors: First, the great complexity of the hydrologic cycle, and second, the lack of adequate observational data, which, when correlated, will permit accurate scientific deductions.

Two phases of water—rainfall and stream flow—are a matter of such common observation that many people, including some technicians not imbued with the scientific method, are apt to think not only that they know a great deal about the behavior of water as it affects man, but by observation not supported by knowledge or reason, to deduce and promote ideas about it which are unscientific and misleading. Dr. Max Mason, president of the Rockefeller Foundation, in discussing "Science and the Rational Animal",[2] has pointed out that man has been so eager in "his desire for causes that a few coincidences determined unjustifiable beliefs which lived for centuries and renewed his store of superstitions." In no branch of natural phenomena is this allegation more apt than in the behavior of water. I assume that it is the purpose of this conference to attempt to enunciate those factors relating to headwater streams and lands which are accepted as demonstrable scientific facts, to discuss frankly observations and ideas still in the realm of hypotheses, and to confess our ignorance of certain facts and processes which we must investigate and coordinate ultimately to achieve a real science of water behavior, of land behavior, and of the intimate relationship between them. It is the purpose of this paper to present certain salient facts, hypotheses, and confessions of ignorance about water behavior.

THE HYDROLOGIC CYCLE

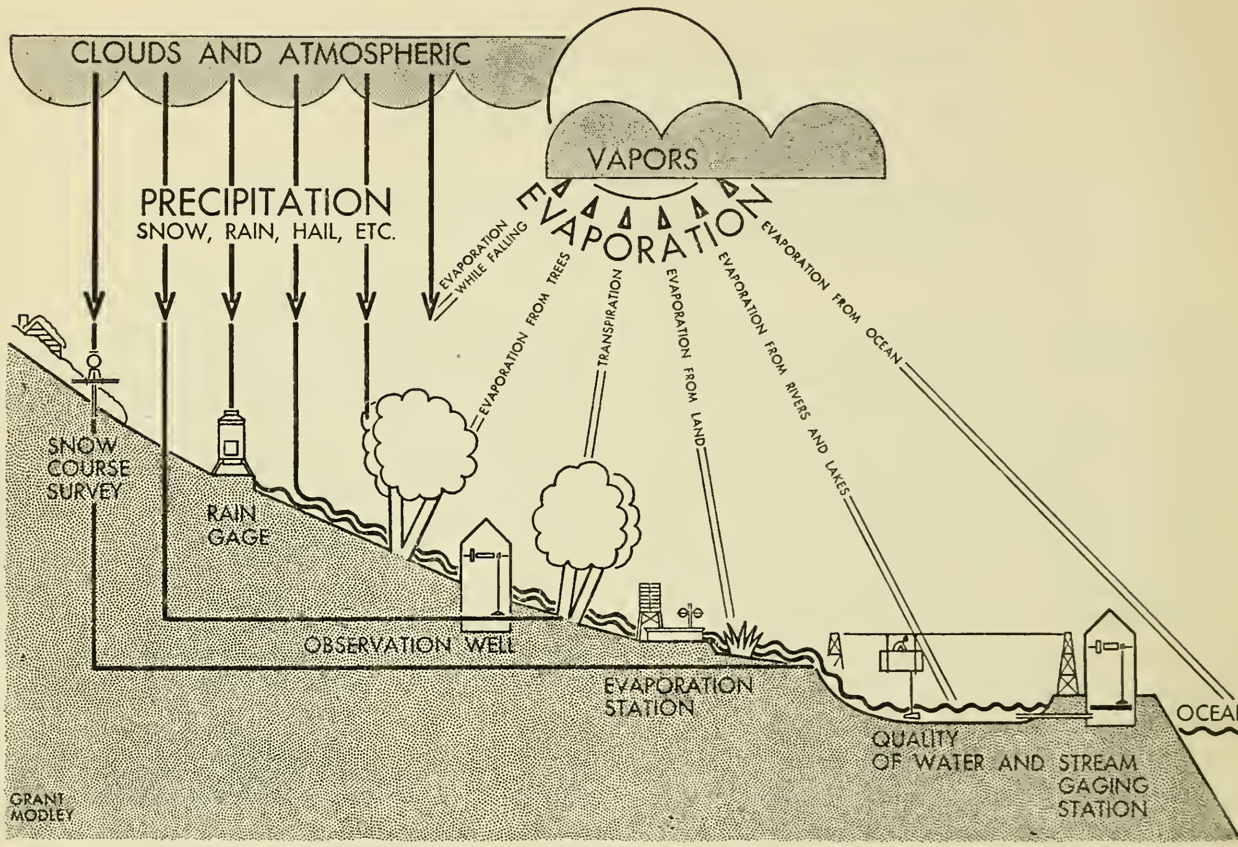
The generalized picture of the movements of water as it relates to the earth is called the *hydrologic cycle*. The most comprehensive diagrammatic representation of these phenomena was published by Horton [3] in 1931. A somewhat less complete but perhaps more readily visualized diagram is presented herein as figure 1. The major elements in the hydrologic cycle are there clearly indicated, but further elaboration is desirable.

1. *Atmospheric moisture*.—All water with which

[1] Significant steps toward this end have been made by Messrs. Sherman, Horton, Bernard, Horner and others, during the past 2 years.

[2] Max Mason, Science and the Rational Animal, *Science*, Vol. 84, No. 2169, July 24, 1936.

[3] R. E. Horton, The Field, Scope and Status of the Science of Hydrology, *Trans. Am. Geoph. Union*, 1931.



National Resources Committee.

HOW THE WATER CYCLE IS MEASURED

FIGURE 1.

man is practically concerned [4] is assumed to originate from atmospheric moisture. This is merely a convenient starting point from which to trace the complete water cycle. Atmospheric moisture consists of water vapor, clouds, and fog. Water vapor is the gaseous state of water, and is present in the atmosphere because of evaporative processes on the land or from water. Clouds and fog represent condensation of water vapor upon such small nucleii (such as salt or smoke) in the atmosphere that the water droplets do not fall as precipitation.

2. *Precipitation.*—When water vapor in the atmosphere is cooled, condensation results, and when the resulting water droplets attain a sufficient size they fall as *rain.* If the raindrops pass through zones of temperature below freezing, *hail* results. If condensation occurs at temperatures below freezing, *snow* is formed. Under some conditions both snow and hail are present, and we then have *sleet.* If condensation of water vapor takes place directly on the surface of vegetation, on account of the vegetation being cooler than the air, either *dew* or *frost* is formed, depending upon whether the temperature at which condensation occurs is above or below freezing.

3. *Precipitation not reaching the ground.*—Some precipitation is evaporated during its fall. This is called ineffective precipitation. Some precip-

[4] This eliminates "internal water" which may exist in the interior of the earth.

itation is intercepted by vegetation, from which it is subsequently evaporated back to the atmosphere. This is called *interception.* Interception may amount to a considerable proportion of the effective precipitation. Naturally, the more vegetation and foliage, the greater the losses by interception. Light summer rains, amounting to one-half inch or more, may be almost completely intercepted and evaporated by heavy foliage. Studies by the Forest Service [5] indicate that from 12 to 40 percent of the summer rainfall is lost by interception and evaporation in timber stands of various kinds. Horton [6] has reported that about 70 percent of light rainfalls and 24 percent of heavy rainfalls are thus lost.

4. *Precipitation reaching the ground.*—Of the precipitation which reaches the ground, some percolates into the ground, some runs off over the surface, and some evaporates.

(*a*) *Infiltration.*—The first tendency of rain or melting snow is to moisten the surface and then to percolate into the interstices of the soil. This is called *infiltration* or *percolation.* The proportion of the precipitation thus disposed of varies greatly with the temperature and with the previous water content of the soil. If the ground is frozen, or if the soil interstices are well filled with water, very little additional precipitation may be admitted. Of the total infiltration some percolates to the ground water and is discharged to bodies of water, some is utilized by vegetation and transpired back into the atmosphere, and some is evaporated by capillary action.

(*b*) *Surface run-off.*—When the rate of precipitation (or rate of application of rain or melting snow to the land) exceeds the rate at which water may percolate into the soil (infiltration capacity) surface run-off usually occurs. This part of the precipitation finds its way over the surface of the ground until it reaches a definite stream channel, through which it is discharged ultimately into the ocean or some inland water body. There is some loss in transit because of (a) evaporation to the atmosphere and (b) infiltration which may vary from practically zero to nearly 100 percent.

(*c*) *Ground evaporation.*—Some of the precipitation is retained on the ground surface, either as a film of moisture or as puddles of water filling small depressions. Following precipitation the film of moisture will usually evaporate; water in puddles may evaporate in part and in part percolate into the soil. On a warm day, and on a tight soil, ground evaporation losses after precipitation may be considerable.

5. *Evaporation.*—Water, in the liquid state, when subjected to heating by solar energy or otherwise, passes into the gaseous state. This phenomenon is called *evaporation.*

(*a*) *Evaporation from water surfaces.*—Of the total precipitation, a very large amount falls directly upon the oceans and large inland lakes, and some falls directly upon other water surfaces, such as rivers, ponds, etc. Practically all such precipitation is ultimately evaporated into the atmosphere and becomes part of the atmospheric moisture. In the Arctic and northern portions of the Temperate Zones, evaporation from water surfaces is frequently less than the precipitation, but the surplus is ultimately discharged to the oceans, from which it is evaporated. Elsewhere, evaporation from water surfaces is generally equal to or greater than the precipitation falling upon them.

(*b*) *Evaporation from the ground.*—This has been discussed in section 4c.

(*c*) *Evaporation from vegetation.*—This has been discussed in section 3.

6. *Transpiration.*—One of the basic factors in the life processes of trees, plants, and other forms of vegetation is to take water from the soil through the roots, utilize it in producing growth and maintaining life, and discharge it from their pores into the atmosphere as water vapor. This process of returning ground water to

[5] *Watershed and Other Related Influences,* U. S. Department of Agriculture, Forest Service, S. Doc. 12, Separate 5, 72d Cong., 1935.

[6] R. E. Horton, Rainfall Interception, *Monthly Weather Review,* September 1919.

atmospheric moisture is called *transpiration*. The amount of precipitation thus returned to the atmosphere varies greatly with the character of vegetation, the soil, etc. It may range[7] from 2 inches to 15 inches or more, annually. Ordinary forest stands or wood lots are generally estimated to transpire about 8 inches of water per year.[8]

Sources of Precipitation

One of the commonly accepted beliefs is that by far the larger part of precipitation on the land comes from water vapor evaporated from the oceans, carried inland over the continents and there precipitated. The facts are to the contrary. Since accurate measurements of sea level, carried on for hundreds of years, show that the level of the sea is substantially constant, it is evident that the amount of precipitation on land resulting from water vapor transferred from the oceans can only be equal to the return of water to the ocean from the land, or the surface run-off. While the exact amount of run-off is not known, measurements of river discharge in various parts of the world are sufficient in number, accuracy, and cover sufficient time to enable a fairly reliable estimate of run-off from lands to oceans to be made. Similarly, measurements of precipitation on land, while lacking in number for certain specific or local engineering and agricultural studies, are ample to evaluate the approximate total precipitation falling on land areas. It is provable that precipitation derived from ocean

[7] U. S. Department of Agriculture, Forest Service, loc. cit.

[8] R. E. Horton, *Hydrology of the Great Lakes*, 1927.

Table 1.—*Quantitative estimates of the hydrologic cycle*

	Amounts in cubic kilometers		Amounts in centimeters		Amounts in inches	
	K[1]	M[2]	K	M	K	M
1. Evaporation from the sea	307, 000	449, 000	85. 0	124. 3	33. 40	48. 50
2. Evaporation from the land	81, 000	62, 000	54. 4	41. 6	21. 50	16. 50
3. Precipitation on land and sea	388, 000	511, 000	76. 0	100. 0	29. 90	39. 40
4. Evaporation from the sea	307, 000	449, 000	85. 0	124. 3	33. 40	48. 50
5. Water vapor transferred to land	30, 000	37, 100	8. 3	10. 3	3. 26	4. 04
6. Precipitation at sea	277, 000	411, 900	76. 7	114. 0	30. 00	44. 60
7. Water vapor obtained from sea (run-off)	30, 000	37, 100	20. 2	24. 9	7. 90	9. 75
8. Evaporation from land draining to sea	71, 000	....	47. 6	....	18. 70	....
9. Precipitation on land draining to sea	101, 000	....	67. 8	....	26. 50	....
10. Evaporation from districts without run-off	10, 000	....	....	....	....	....
11. Precipitation on districts without run-off	10, 000	....	....	....	....	....
12. Water vapor from ocean (or from ocean plus evaporation from lands not draining to ocean)	40, 000	37, 100	26. 8	24. 9	10. 5	9. 75
13. Evaporation from all land areas	81, 000	62, 000	54. 4	41. 6	21. 4	16. 4
14. Precipitation on all land areas	121, 000	99, 100	81. 2	66. 5	32. 0	26. 1

[1] Dannye i myslio krugovorote rody no semnon share, A. A. Kaminsky, *Izrestia Tsentralnogo Gidrometeorolicheskogo Biuro*, Vyposk 4, 1925.
[2] Die Niederschlagsverteilung auf der Erde, W. Meinardus, *Meteorologische Zeitschrift*, Band 51, 1934.

Estimated percentage of precipitation on land areas from water vapor from sea equals 33 percent by Kaminsky and 37.4 percent by Meinardus.

evaporation varies from 3 to 75 percent of the total, and that the average for the United States is less than 30 percent. The greater part of the precipitation over continental areas is derived from condensation of water vapor evaporated from those land areas. Two recent estimates of the relative values in the hydrologic cycle are of interest and are presented in table 1, since they have not been previously published in this country.

Complexity of Hydrologic Cycle

The phenomena of precipitation, infiltration, run-off, evaporation, and condensation to precipitation again may appear an obvious and simple cycle of natural events, especially as pictured in figure 1. While we know all of the factors which make up this life-giving cycle, we are woefully ignorant about the relationships between them, which are essential to a scientific approach to many problems of land and of water use.

In the first place, the elements of the hydrologic cycle vary enormously, not only throughout the country, but from year to year and from season to season. The latest information on precipitation in the United States is to be found in part III of the report of the National Resources Board, 1934, and indicates variations in annual amounts from over 200 inches, over part of the Cascade Range, to 5 inches or less in the Great Basin. The latest map of annual precipitation over the country indicates the very first obstacle to any simple relationship between rainfall and other elements of the hydrologic cycle; namely, the very uneven distribution of precipitation over the United States. Other maps show additional obstacles to be the great variations in monthly distribution of precipitation and of run-off over the country.

Let us bear clearly in mind that such maps are based on average figures—that they probably never represented the relationships of rainfall and run-off that ever actually occurred—that in any one year the average precipitation may have departed 20 percent to 50 percent above or below the average—that the run-off may have varied almost as much in the opposite direction—that losses by transpiration and evaporation are so inadequately measured that we cannot even venture to delineate the average conditions on a map. All of this is but a taste of the complexities one runs up against in attempting to be specific and quantitative about the hydrologic cycle.

But this is only the beginning of our difficulties. We measure rainfall with fair accuracy, perhaps with an error of 5 percent to 10 percent considering the country as a whole. We measure stream flow with better accuracy, perhaps within an error of 3 percent to 5 percent for the country as a whole. We have 6,800 precipitation stations and 3,100 stream-gaging stations. Even so, our detailed knowledge of rainfall and of stream flow is almost nonexistent when applied to small drainage areas of 10 to 200 square miles. We know a good deal that is accurate about rainfall and run-off on many large drainage areas where details can be averaged, but we know very little about details of these two long-measured factors on small drainage areas.

But let us not wander into the frequently traveled, though utterly unscientific, paths of rainfall-run-off relationships, for nothing is more fallacious than to assume any simple or direct relationship between rainfall and run-off. Properly speaking, run-off is merely the residual from precipitation after all other dispositions have been made. As illustrative, the following table [9] shows clearly how dangerous such generalizations may be:

	1910	Rain-fall	Run-off
		Inches	*Inches*
Upper Scioto River	March	0.32	2.91
	September	4.37	.02
Miami River	March	.04	2.59
	September	6.08	.51

[9] J. C. Prior, *Run-off Formulas and Methods Applied to Selected Ohio Streams,* Engineering Experiment Station Bulletin 49, 1929.

The run-off varied from less than 0.5 to 6475 percent of the rainfall on two neighboring Ohio streams. Obviously, infiltration, transpiration, and evaporation were important factors. But it is here that we suffer so from lack of observational data. There are less than 100 standard water evaporation stations in the country. Accurate measurements of transpiration from various kinds of vegetation are exceedingly limited, and have been conducted in this country only upon an insignificant scale. Yet water losses from transpiration by vegetation may represent very large quantities otherwise available for stream flow. Of infiltration rates for the soils of the country we know next to nothing. Of ground-water levels, so important in any qualitative evaluation of the disposal of precipitation and the results of land improvement practices, we have virtually no program of systematic observations. Few ground-water level records extend over more than a 2- or 3-year period.

Folse,[10] in an exhaustive study with Hayford in 1929, decided that some 22 factors had to be considered in order to predict the run-off from a given rainfall. Zoch, in two monographs published recently,[11] has derived highly involved mathematical relationships between rainfall and resulting run-off. More practical attempts to correlate rainfall with factors which will enable run-off to be predicted have been made by Sherman[12] in 1932, by Bernard[13] in 1934, and by Horton[14] in 1935. In Horton's paper there are 10 factors listed as determining direct surface run-off: (1) Rainfall intensity, (2) distribution of rainfall over the area, (3) duration of rainfall, (4) initial detention of water on the ground, (5) velocity of overland flow, (6) infiltration capacity, (7) ground-water flow, (8) channel detention, (9) flattening of flood waves because of friction, etc., in traveling downstream, (10) combination of wave crests from different subareas. These are the factors required to determine quantitatively the run-off from a given rainfall, and certain of these factors require additional data for their evaluation.

With these factors in mind, how unscientific it is to make broad generalizations as to what some specific treatment of a soil will do for water conservation when we do not know what the infiltration rates of the soil are, how they may be affected by temperature, previous precipitation, slope, and other factors, or what the transpiration and interception may be under such differing conditions.

SOME SPECIFIC PROBLEMS IN THE HYDROLOGY OF UPSTREAM ENGINEERING

1. *Vegetative cover, stream flow, and floods.*—This is perhaps as controversial a subject as there is, with respect to assertions and allegations concerning the hydrologic cycle. Only two scientific, controlled experiments have been reported in this country, in spite of all the welter of talk. Both were on extremely small areas, representing special and different conditions of elevation, soil, and rainfall. One was the Wagon Wheel Gap, Colo., experiments [15] on two areas 225 and 200 acres, respectively, at elevation of about 10,000 feet. The other [16] was on two southern California streams of 6.5 square miles and 10.5 square miles, respectively. These are noteworthy, chiefly because they represent carefully conducted experiments, reported in the technical literature, and subject to informed discussion.

[10] J. A. Folse, *A New Method of Estimating Stream Flow*, publication 400, Carnegie Institution of Washington, 1929.

[11] R. T. Zoch, On the Relation Between Rainfall and Stream Flow, *Monthly Weather Review*, vol. 62, September 1934, and vol. 64, April 1936.

[12] L. K. Sherman, Stream Flow from Rainfall by Unit Graph Method, *Engineering News Record*, Apr. 7, 1932.

[13] Merrill M. Bernard, An Approach to Determinate Stream Flow, *Trans. Am. Soc. C. E.*, vol. 100, 1935.

[14] R. E. Horton, *Surface Run-Off Phenomena: Part I, Analysis of the Hydrograph*, Publication 101, 1935. Horton Hydrological Laboratory.

[15] Forest and Stream Flow Experiments at Wagon Wheel Gap, Colorado, *Monthly Weather Review*, Supplement 30, 1928.

[16] W. G. Hoyt and H. C. Troxell, Forests and Stream Flow, *Trans. Am. Soc. C. E.*, 1932.

Moreover, both rainfall and stream-flow data were reasonably accurate, the details of both were known and something was known of the character of the soils. However, no data were available on ground-water changes, infiltration, or transpiration.

From these very limited experiments and from less accurate observations elsewhere, three definite generalizations may be drawn:

(*a*) Removal of vegetative cover will appreciably increase the surface run-off from precipitation, or, conversely, forestation or vegetation reduces the average flow of water in streams.

(*b*) The ordinary flood heights are reduced in magnitude by forestation or vegetative cover.

(*c*) There is less erosion when the soil has a forest or proper vegetative cover.

These are generalizations which few will dispute. It is in their quantitative aspects that enthusiasts may lead the public astray. Let us consider a small denuded drainage area of, say, 10 square miles. The following questions are pertinent:

1. If the area is reforested, will the interception and transpiration losses (amounting often to 30 percent of the low-water flow) be such as to reduce the low-water or summer flow to such an extent as seriously to impair the water-supply uses of the stream?

2. If the area is improved by a mixture of forest (with large transpiration losses), and other vegetation having equally good erosion-prevention characteristics but less transpiration loss, what will be the effect upon run-off from very intense precipitation? How much will appear as surface run-off, how much will be transpired, and how much will infiltrate into the ground-water horizon?

3. How will these factors vary with temperature, elevation, snow cover, etc.?

Until these and other hydrologic questions can be answered quantitatively, we should proceed with caution in the expenditure of public funds for small watershed improvements. The writer has previously expressed the hope that a definite and coordinated scientific program will be formulated and carried out by Federal agencies, which may supply much of these data.

It should be pointed out, however, that it is not enough, from a scientific hydrological standpoint to cite plot experiments where, for instance, the percent of rainfall appearing as surface run-off is reduced from, perhaps, 40 percent to 1 percent less, by improved soil cover. In the first place, no information appears from such experiments as to what happens to the water that did not run off from the improved plot. How much was ultimately recovered as ground water, and how much was lost by evaporation and transpiration? In the second place, plot experiments must be regarded as indicative only; that is, elements in the hydrologic cycle, reported from experiments on small plots, are exceedingly unlikely to be duplicated if the experimental results are applied to drainage areas of 10 to 100 square miles. The larger scale experiments now planned should produce more exact results, especially if conducted in accordance with a program whereby different scientific and technical interests may be effectively coordinated.

Furthermore, there is great need of coordination of experiments. For instance, not only have plot experiments shown that certain types of soil cover reduced surface run-off appreciably, but other experiments [17] have shown that forest litter markedly increases infiltration capacity of soils. Still other experiments indicate transpiration effects, and others, the equalization of run-off and silt reduction by soil-conservation practices. Other experimental data show contrary results. Most of the experimental observations thus far published relate to isolated measurements of one or two single factors in the hydrologic cycle. Often, quite unwarranted conclusions have been drawn from these, because other factors were not

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[17] W. C. Lowdermilk and P. B. Rowe, Still Further Studies on Absorption of Rainfall in its Relations to Surficial Run-off and Erosion, *Trans. Am. Geoph. Union*, 1934

considered. Lowdermilk [18] has presented an admirable summary of some of these difficulties. There already exists a large amount of factual material, most of it uncoordinated. More is being collected daily by several Federal agencies. It will be a great pity, and a serious blow to scientific consideration of land and water conservation measures, if a definite program of investigation, publication, and discussion is not promptly worked out whereby these numerous studies may be impartially planned, and coordinated from all points of view.

2. *Small ponds.*—One water conservation enthusiast has recently proposed some 50,000 farm ponds for a Midwestern State in the drought area. Let us consider a few quantitative facts about this subject.

(*a*) If built prior to the effective establishment of soil-erosion prevention measures, how quickly will their utility be markedly impaired by filling with silt?

(*b*) If even a moderate silt content exists in the entering water, will it not seal off the bottom and prevent desirable infiltration to ground water?

(*c*) What will be the evaporation from the water surfaces of these ponds? Will it be sufficient to impair their usefulness in time of drought? Often, annual evaporation is more than half the storage capacity of a reservoir.

(*d*) If soil erosion measures are practiced above the ponds, may the low-water flow be so reduced by transpiration losses that the utility of the ponds for drought prevention purposes will be impaired?

(*e*) If the ponds are kept full for drought relief and recreation purposes, to what degree are they useful in flood prevention? Cloudburst floods on small drainage areas frequently come during the dry period of the year.

(*f*) Is information available as to the magnitude and frequency of intense precipitation and flood flows? Hundreds, and probably thousands, of ponds formed by small dams have been destroyed within recent years by flood flows which surpassed the spillway capacity of the dams. Little is known about flood flows from small drainage areas.

The writer regards farm ponds as potentially important factors in improved water-conservation measures, as sources of water in drought periods, as contributors to ground-water replenishment under certain favorable conditions, and as desirable in other ways. But before embarking upon large programs of construction, most of the hydrologic questions enumerated above should be considered.

3. *The ideal upstream drainage area.*—The writer does not know where "upstream" engineering ends, or where "downstream" engineering begins. But, for the sake of argument, let us suppose that every stream having a drainage area of 100 square miles or less was thoroughly subjected to "upstream" engineering practices. These are presumed to include soil-erosion control by reforestation, improved vegetative cover, improved agricultural practices, check dams, etc., and watershed improvement by the same measures and by farm ponds. In addition to the questions propounded previously we must ask the following:

(a) To what extent will the average and low-water flow of the lower parts of the drainage basin be reduced by the upstream engineering practices? Will the effect be sufficient to cause injunction proceedings or damage suits from water power or municipal water supply interests downstream?

(b) Will the reduction in silting of downstream reservoirs compensate for the reduced annual flow?

(c) Under what conditions may the effects of losses by transpiration be compensated by improved soil conditions leading to greater infiltration, to ground water and subsequent regularization of stream flow and increase in low-water flow?

[18] W. C. Lowdermilk, The Role of Vegetation in Erosion Control and Water Conservation, *Journal of Forestry*, vol. XXXII, no. 5, May 1934.

(d) Will the beneficial effects on ordinary or small floods be sufficient to justify the improvements as part of a flood-control program? To determine this, the quantitative effect of the improvements as to their flood-control potentialities must be susceptible of evaluation.

(e) The improvements are unlikely to affect the magnitude of the largest floods, but even in moderate floods the questions should arise: What will be the effect of numerous small ponds upon such floods? Will the timing effect of the discharge from such ponds produce larger crests at downstream points than formerly? This is possible, although hardly probable in many instances.

(f) If farm ponds are constructed as drought-relief and recreational assets, to what extent may they be effective in flood control? Are not the probabilities that the ponds will be kept as full as possible, and that their flood-retarding potentialities will be slight? If not, a definite system of pond-level control must be instituted, a task of no mean proportions.

(g) Assuming wild-fowl protection as part of the upstream engineering program, what is the price of the differential between large water losses by evaporation and transpiration from swamps desired for wild fowl and the rapid delivery of water from upstream ponds to downstream communities by improved channels where there is a dearth of rainfall for domestic and irrigation needs?

CONCLUSION

The writer has long been an advocate of forestation and soil-erosion control. He has seen too many instances of the beneficial effects of headwater forests in the Southern Appalachians and too much of the sad effects of erosion of the southern Piedmont lands not to be highly sympathetic with any program which proposes to enhance the conservation of our water and land resources. As an engineer, he knows that it is possible to design a water-conservation structure, such as a reservoir, to determine within a very small percentage of error what magnitude of flood it will hold, what it will do for low-water control, and what it can produce in water power. By a definite system of management a reservoir may be accurately designed to perform one or a number of services, and not only will effective management permit these to be carried out but the appropriate costs as against flood control, power, navigation, low-water control, etc., may be fairly accurately allocated.

When we come to upstream engineering, we enter a far more hypothetical realm. We do not know as yet the basic elements of the hydrologic cycle or their interrelationships. We need many more rain gages, stream gages, snow surveys, evaporation pans, transpiration and infiltration measurements, etc. A special report outlining the need and a program for expanded activities for the collection of hydrologic data has just been published by the Water Resources Committee of the National Resources Committee. This report is entitled "Deficiencies in Basic Hydrologic Data." It analyzes the existing facilities for the collection and publication of such data; indicates the serious consequences in loss of life, bad design, failures of water undertakings, etc., from lack of such information; and outlines a minimum comprehensive continuing program to provide these vital data necessary to any proper water-conservation activities. It contemplates the addition of 1,200 new cooperative rainfall stations, 400 recording rainfall stations, 500 snow-survey courses, 500 base and 600 cooperative stream-gaging stations, 4,000 wells for basic ground-water observations and 6,000 wells for secondary cooperative observations, 30 first-class and 250 second-class evaporation stations, 200 base and 400 secondary quality-of-matter stations, together with a program of coordination and publication. The recommendations of this report were exceedingly carefully considered by a competent group of experts, and the scope of the report is indicative of our great need for additional basic hydrological data.

But even the thousands of new stations recommended in this report will not provide the detailed data requisite for quantitative evaluations of upstream engineering practice. The writer has attempted in this paper to stress the need for detailed studies of the hydrologic cycle on drainage areas of from 10 to 100 square miles. It is not enough to report the success of this or that experiment which evaluates only one or two elements in the hydrologic cycle. We must be more thorough going and consider the relationship of all of the elements of the cycle to any large-scale upstream engineering undertakings. The promising future for more rational conservation of our headwater land and water areas ought not to be compromised by many striking failures to produce promised results because of lack of adequate knowledge of the hydrologic cycle and the factors that modify it in different parts of the country. The writer pleads for an honest scientific program of research in headwater land and water conservation, or in upstream engineering, a program carefully conceived by joint conference between various Federal and other governmental agencies concerned with various aspects of the problem, assisted by the advice of nongovernmental experts.

In all that has been said heretofore, two vital elements in upstream engineering have been omitted. Their consideration is not the function of this paper, but passing mention of their importance is believed justified. The first is the relationship between land-conservation measures and water-conservation measures. It makes no difference how justifiable a land-conservation program may be per se; that is, no matter how well warranted soil-erosion measures, check dams, vegetative cover, reforestation, improved agricultural practices, etc., may be from a land-conservation standpoint, it does not necessarily follow that these same measures may be justified in the same degree or even in a much lesser degree from a water-conservation standpoint. If there is inadequate precipitation, no amount of land improvement can make any more. In some soils, and under some conditions, the land improvements may be highly beneficial to water conservation. Under other conditions, little benefit to water conservation may result. The relationship between the two depends upon knowledge of the hydrologic cycle.

The second element is that of economics. Upstream engineering, if reasonably effective, is likely to be costly. The results in many cases will be worth the expenditure. In some cases they will not. The relationship between the elements of the hydrologic cycle, between land conservation and water conservation, and the benefits to be expected from the improvements all rest on facts which ought to be determined in a scientific manner.

It seems to the writer that in this matter of upstream engineering it is vitally important that any program be conducted and developed by truly scientific methods. May we not follow the advice of Francis Bacon, given centuries ago, when he said, in describing the man of science, that he had "the desire to seek, the patience to doubt, fondness to meditate, slowness to assert, readiness to reconsider, carefulness to dispose and set in order, and hating every kind of imposture."

DISCUSSION

1. William Peterson
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Professor Saville has given a very fine and comprehensive picture of nature's hydrologic cycle. He has outlined this procedure, however, on the basic principle of a general normal behavior of water in all stages. The disturbing influence in the West does not seem to be a strictly normal behavior, and it is about some phases of unusual behavior that I should like to discuss.

The relative humidity of the atmosphere in the West is low, especially in the summer months. Normal humidity is about 30 percent, but measurements as low as 10 to 15 percent at 6 p. m.

are not unusual during July and August. Storms come essentially from the Pacific Ocean area, and seldom does a storm form locally, even in the high mountains.

The rate of evaporation is high. The Weather Bureau reports normal evaporation on the west side of the Wasatch Mountains between 45 and 55 inches in average years. The evaporation from Great Salt Lake, at an altitude of 4,219 feet, is 60 to 80 inches annually. At St. George, in the southern part of Utah, with an altitude of 2,880 feet, which has a high annual temperature and little precipitation, the evaporation is 90 inches. At Fort Duchesne, with an elevation of 4,940 feet, the evaporation is 75 inches. Records gathered on the desert at the Saldura salt works, at an elevation of 4,220 feet, showed an evaporation of 8 inches in May, 13 inches in June, 14 inches in July, 14 inches in August, and 8 inches in September. Evaporation directly from snow surface reported from the experiment station at Ephraim, at an elevation of 4,750 feet, approximates a total of 3 inches during the snow season of 180 days.

The water surfaces in the West are small compared with the land and have a relatively low humidity. These facts are only mentioned to emphasize that the phenomena of bringing such an atmosphere to supersaturation are very different than in areas of high humidity. In the vicinity of Washington, D. C., a rainstorm seems to start without any special preparation. The humidity becomes high, the atmosphere feels depressing, and the next thing you know it is raining. Summer storms in the West do not behave in this fashion. The precipitation of winter is usually quiet and with no unusual occurrence, but in the summer months it may be quite different. Weeks may elapse without any rain whatever; the sky may be clear for many days without a single cloud. When a storm does come, it is usually with intensive atmospheric disturbance. I do not want to give the impression that all summer storms are erratic. They are not; but it is the occasional one with abnormal behavior that does great damage, and it is this unusual behavior with which we are most concerned.

The abnormal behavior usually begins with massive black clouds in only a portion of the sky; the balance of the sky may be clear. There is a sudden drop of the barometer, high winds, spectacular lightning and thunder. The storm travels rapidly, as much as 10 to 20 miles per hour. The rain falls in unusually large drops; the rain may strike the earth at a high angle, 30° to 60° from the horizontal being not unusual. The storm is often very restricted in area, covering only a narrow path and may endure only a few minutes or a few hours. It may end in a clear sky or a quiet rain. The falling rain from such a storm is not only erratic in intensity but it is irregular in position.

One who is not accustomed to mountains and valleys of high relief might ask, "Why is a knowledge of this erratic water precipitation necessary?" Erratic storms have always occurred at intervals and will, in all probability, continue to occur. There is a very definite reason for wanting more data regarding the accurate behavior and rate of precipitation from the torrential storms in the arid West.

Before men came to take possession of the lands, nature seemed to have established a balance or stability. The soil surface area and topography seemed to be fixed. Drainage had been established and the surface of the hills and mountains seemed stable, although with high gradient. The basic elements involved in the balance included: (1) The soil type of which the land surface is composed, (2) the gradient or slope of the land, (3) the amount and type of vegetative cover, and (4) the rainfall with its variable rate and behavior. These, of course, were influenced by many other elements, such as temperature, rate of snow melting, wind-blown snow, etc.

In the settlement of the mountainous areas, towns have been built near the edge of steep mountains, usually at the mouths of canyons.

The canyons are often steep, drain a comparatively small basin, and often head in glacial cirques at high elevation. These settlements have felt secure and have lived without disturbance for a long period. There has been no appreciable change in the soil or gradient, but the changing element which disturbs the balance or stability of nature is principally the vegetative cover. This is first affected by the erratic behavior of the rain and melting snow.

When one reads the rainfall record over a series of years it may seem to be quite comparable one year with another, but the mere record of the total rainfall is not sufficient to make the interpretation. As Mr. Saville has stated, the rainfall may be as much as 50 percent more than the mean or 50 percent under the mean; but whatever may be the record, it is the single rainstorm of unusual behavior with which we are concerned. It is in the late summer months of July and August that these erratic storms most often occur in the West. They do not seem to occur with any regularity and at present there seems to be no warning as to when they will come and how they will behave.

An inch of water in a day would be recorded as a heavy rainstorm in the West. But an inch of water in an hour or as much as 2 inches in an hour, which has been estimated, is an intensity which may be tremendously disturbing as far as nature's balance is concerned. The vegetative cover on certain soils and certain slopes may be just enough to hold the area in balance with a maximum of one-half inch rainfall per hour, but an inch of water will cause disintegration and possibly flood damage.

Much of the area concerned in settlement and industry is just in balance. A stock trail on the side of the mountain or a drag road where timber is taken down the mountain is sufficient to develop a deep gully, even though the area on either side, with the same soil type, same rainstorm, and vegetative cover, offers sufficient resistance to increase the ground absorption, retards the rate of flow and endures without damage. The high gradient in many of the steep canyons of the mountains gives to the stream a carrying capacity much beyond that which the stream can carry at the low gradient in the valley. The debris from a flood is piled up as cones or fans where the water loses its velocity. Where villages are built close to the mountain, irrigation works, roads, public buildings, etc., are often damaged or destroyed by such floods. These damaging storms may come only occasionally but it is only sensible to be prepared on the assumption that what has been recorded may come again.

Let us analyze this intensive rainstorm for a moment in one other fashion. We are told that when rain falls on the earth a portion of it flows over the surface, a portion evaporates and a portion goes into the earth either to make a contribution to the ground-water recharge or again to appear through the transpiration of plants. The absorption into the ground-water recharge is influenced by the type and porosity of the soil as well as the time element. Heavy argillaceous soils are of a type that absorb water very slowly. The West has appreciable areas of such soils which are typical in the weathering of the Dakota and mancos shales of the cretaceous and Green River and Bridger beds of the tertiary. In most areas these types of soils are not in balance and are poorly vegetated.

When a heavy rainstorm strikes the dry surface, the first action seems to be to fill the interstices between the fine particles making up the clay soil and produce an almost impervious layer near the surface. The penetration of such soils is very small and the run-off is very rapid. It has been estimated that on the mancos shale areas as much as 75 to 90 percent of the water runs over the surface during a heavy erratic storm. It is not unusual to see one of the drains suddenly change from a dry wash into a stream of 200 or 300 second-feet of water which may flow for only an hour. This type of water behavior has led to intense erosion and also has

the effect of giving little water to the underground supply. Often such streams are entirely spent along a dry channel and do not reach either a live stream, a pond, or a lake.

One may attempt to apply a mathematical formula to this action, note that the velocity of the stream varies almost as much as the volume, and that the carrying power may vary approximately as the sixth power of the velocity. While the formula may be correct, the basic behavior of the stream is changing so rapidly that it is hard to apply it except in a general way. At one time the stream may carry a 10-, 15-, or 20-percent sedimentary load. A few minutes later its load may be much more or less and its gravity and velocity changes. How scientific knowledge will apply to such phenomena is yet, in a measure, conjecture. It should be remembered, however, that it is this type of water behavior that influences the amount of sediment that is carried into the rivers.

TABLE 2.—*Silt deposited by Colorado River, 1903–35*

Year	Acre feet	Year	Acre feet
1903	73, 270	1921	111, 894
1904	69, 332	1922	95, 407
1905	138, 685	1923	125, 145
1906	132, 295	1924	62, 365
1907	161, 252	1925	86, 336
1908	104, 223	1926	69, 482
1909	155, 765	1927	119, 293
1910	100, 145	1928	61, 708
1911	127, 220	1929	143, 478
1912	107, 985	1930	89, 396
1913	81, 630	1931	28, 144
1914	120, 845	1932	99, 480
1915	107, 860	1933	49, 035
1916	204, 834	1934	8, 733
1917	89, 062	1935	11, 665
1918	59, 831		
1919	68, 333	Total	3, 186, 957
1920	122, 829		

Data from the Reclamation Service, Yuma, Ariz.

In table 2 is presented a record of the silt deposited by the Colorado River as reported by the Reclamation Service at Yuma from 1903 to 1935. During this period the average annual silt deposition was approximately 100,000 acre-feet, or a total of 3,186,957 acre-feet for the period. The highest deposit was 204,834 acre-feet in 1916, and only 8,733 in 1934. The silt deposit is not an index to the total flow of the river, but it is influenced by the erratic floods resulting from the rainstorms or sudden melting of snow upstream. It is not the normal flow of the stream alone that is filling our reservoirs. It is also the unusual flood resulting from heavy rains associated with soil disintegration from areas which have lost nature's stabilizing balance.

The amount of water which falls on the land and is absorbed into the ground-water reservoir depends on (1) the porosity of the soil or rock, (2) the topography of the surface, (3) the rate of rainfall, (4) the amount of vegetation on the surface, and (5) the dryness of the atmosphere. The more rapid the rain falls the less the proportion that sinks in. Loose or sandy soil takes in the water more rapidly than clay soils. If soil has a vegetative mulch in its upper surface, both the rate and amount of absorption is increased. Vegetation restrains the flow of the surface water and holds it longer on the surface; as a result, there is more time for the water to sink in, and less runs off.[19]

If the water passes off quickly there is little absorption, and if the vegetative cover, which forms a physical hindrance to the flow of water, is removed it would immediately have its influence on the amount of water which is absorbed into the ground. Observation in the study of underground water and the possible amount of recharge to the underground supply has led to rather conclusive evidence that there are large areas in the West in which the rainstorms occurring during the summer—that is, from May to October—contribute little or nothing to the underground recharge. This intensifies the problem for making economic use of the western ranges in the development of watering holes or maintaining springs. It emphasizes the problem of water storage and filling of reservoirs. In areas where the soil has a low absorptive capacity, it is not unusual to find a canyon in the western mountains that has no

[19] From *Physiography* by R. D. Salisbury, p. 82.

spring or permanent stream. These areas, however, are utilized for grazing and water must be provided either through wells or reservoirs.

I have great hopes that the Weather Bureau will develop to a point that its forecasting might include something as to the type of storm predicted as well as just predicting a storm. I hope that our rain gages in the future will be rate rain gages, telling us not only the amount but the rate at which rain falls in different localities, and that the rain gages will be greatly increased in numbers. With these data, the engineering necessary to control flood damage and erosion is hopeful.

Today we are spending large amounts of money to substitute physical works that will retard the flow of water as the vegetative cover formerly did it. To do this intelligently it is absolutely necessary to know the problem; and to meet the problem we must know the rate of rainfall, the type of storm to expect, the rate of stream flow, and the basic principles of their behavior. If these data are available I have faith in the engineering skill being able to solve the problem.

There are some of us who have emphasized this erosion problem for more than 2 decades. Almost suddenly the country seems to have grown conscious of the fact that there is an erosion problem. This erosion is robbing the Nation of its wealth. We will never completely stop erosion. It is the natural behavior of water to run downhill and to remove some earth particles with it. It is the natural behavior of rain to absorb carbon dioxide and other gases from the atmosphere. This gives a solvent power which is especially effective in limestone areas. The lime will continue to be dissolved out of the soils, and, as the late Mr. Marbut said, all limestone soils are on the road toward acid soils. While we will probably never be able completely to stop erosion, there is hope that we may change it from an abnormal to a normal rate.

When we have learned to recognize the erratic behavior of rainstorms and prepare for them, there is hope that we will be able to control the erratic flow of streams and keep them within the scope of normal behavior. If this can be accomplished we have made a great step forward.

2. LeRoy K. Sherman

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Professor Saville has presented us an examination paper with a hard set of questions. No diploma in upstream engineering is to be given to those who do not complete the course of investigation, research, and study which will enable them—not merely to answer—but to prove their answers to these practical questions. This is as it should be.

It is our duty to those State and Federal executives, who in recent years have sponsored works in the study, control, and utilization of water resources, to see to it that the proposed works are built upon a sound scientific and economic basis. Ill-advised plans, based upon half-baked ideas of well-meaning enthusiasts, spell failure and the betrayal of a trust. Saville's plea of caution is not the criticism of hostility. His are the words of a friend intent upon our success.

The objective in Saville's address is so important, and with which I so thoroughly agree, that I am tempted to cite corroborative evidence. His message, however, needs no support. It is the ideal preliminary for this meeting.

Therefore it may be more interesting, and perhaps instructive, if I use the microscope and point out a few flaws, flyspecks, omissions, etc.

The paper emphasizes our ignorance in certain realms of hydrology. This ignorance may be construed by the above-mentioned to the effect that his ideas and conclusions are therefore at least as good as any of the others. To recognize and use what is known, what has been explored, and what has been found is quite as important in scientific progress as it is to recognize what is yet unknown. Thomas Edison said

in effect: "Before I start a research into an undeveloped sphere, I first try to learn what the preceding pioneers have done."

Individually our knowledge of the broad hydrologic cycle may be meager. Perhaps we might answer one or two of the questions propounded. Collectively we are not so woefully ignorant. Hydrology, as an essential to engineering works, is old. Much of it was empirical and some of it is now obsolete. The findings of Colonel O'Connell, R. E.,[20] in 1868 are in accord with the procedure now efficiently used in determination of the rainfall-run-off relation from urban areas. Hydrology as a science is young. The literature, however, is extensive. Great progress has been made in recent years. Some of the best researches come from Italy, France, India, Russia, and other European countries which have organized hydrologic agencies.

The section of hydrology of the American Geophysical Union is the American representative of the International Association of Hydrology. It is a part of the National Research Council, of Washington. The American section was formed in 1931 and now includes most of the leading hydrologists of the United States. Many of them are in this conference today. Some are now attending an international conference in Scotland. The members of this section of hydrology will heartily cooperate in the work of this conference. They will also be merciless critics of unscientific procedures, propaganda, or conclusions.

Professor Saville speaks of the lack of hydrologic data. Collection of data is and should be a continuing procedure. It is not now and never will be completed. However, a very large amount of it has been collected. We are further behind in the study, analysis, and interpretation of data than we are in the collection of data. Data, by themselves, are of little value. It is the interpretation of these data that counts. Much material has been collected and some of it analyzed, then stored away in musty vaults for the spiders to read—lost to the world. Some of this was put aside because the material did not support a particular hypothesis, some because it appeared 20 years prior to the development of scientific interest and more of it is lost owing to lack of an adequate medium for publication and discussion. Probably the greatest need for data is in connection with the investigation of particular phases of the hydrologic cycle—such as infiltration. Here quantitative results require segregation of numerous coincident phenomena or factors.

The comparison of monthly rainfall and run-off on the Upper Scioto and Miami Rivers is a good example of illogical and unwarranted combination of statistical data. The fallacy of drawing a conclusion from such grouped data comes not only from negligence in omitting the three factors mentioned by Saville but the common error in using monthly time limits. The rainfall-run-off relation on a given basin is perfectly consistent if the period of run-off is matched with that producing rainfall.

This leads to the author's remarks regarding "complexity of the hydrologic cycle." Quite true. In earlier engineering writings the phenomena were called "erratic." This was man's alibi for ignorance. No natural laws are erratic. In quantitative analysis it is often proper, when relative effects are known, to combine certain factors, even though some approximation is involved. Final analysis of most of the complex phenomena generally results in simple conclusions.

[20] *Proc. Inst. C. E.*, v. 27, 1867–68, pp. 204–205.

CHAPTER II

SURFACE RUN-OFF CONTROL

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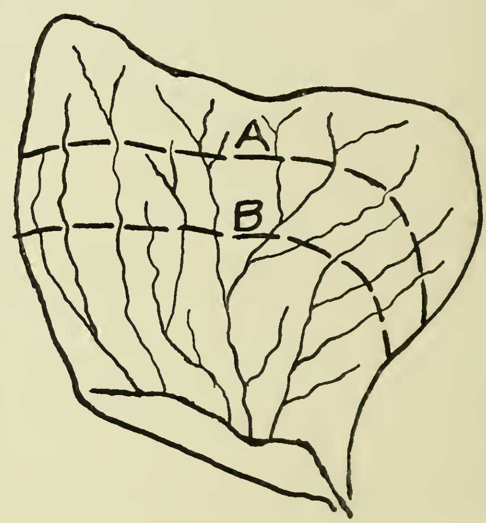
INTRODUCTION

THIS MEETING has been called as a conference on "upstream engineering." Its apparent objective is to bring about the application of sound physical and engineering principles and practice to the mutual relationships between soil and water with a view to the conservation and better utilization of both. A large portion of what is proposed in the caption "upstream engineering" can be accomplished through the control of direct surface run-off.

Surface run-off may be thought of as comprising two phases: (1) Direct surface run-off; (2) channel flow. For the sake of clearness it is necessary to explain where surface run-off ends and channel flow begins. It is convenient and sufficiently precise to include, as surface run-off, sheet flow and ephemeral flow in fortuitous, nonpermanent surface channels and gullies, run-off which ends within an hour or two, at most, after rain ends, and generally ends by the time the water has disappeared from minor depressions and flat areas of land. Channel flow, on the other hand, may be taken to include not only flow in all waterways in which there is a perennial flow, but that in small valleys and even gullies in fields, if they are not plowed and if flow in them persists for some hours after rain ends. Flow in larger artificial drain ditches and even in the ditches behind Mangum terraces partakes of the nature of channel flow, so that it may generally be classed therewith.

Surface run-off control is not confined to the headwater reaches or first order tributaries of streams. Whatever may be accomplished in this respect applies to any portion of a drainage basin upstream or down. Around the margin of a large drainage basin there is usually a belt of land crossed only by intermittent or ephemeral

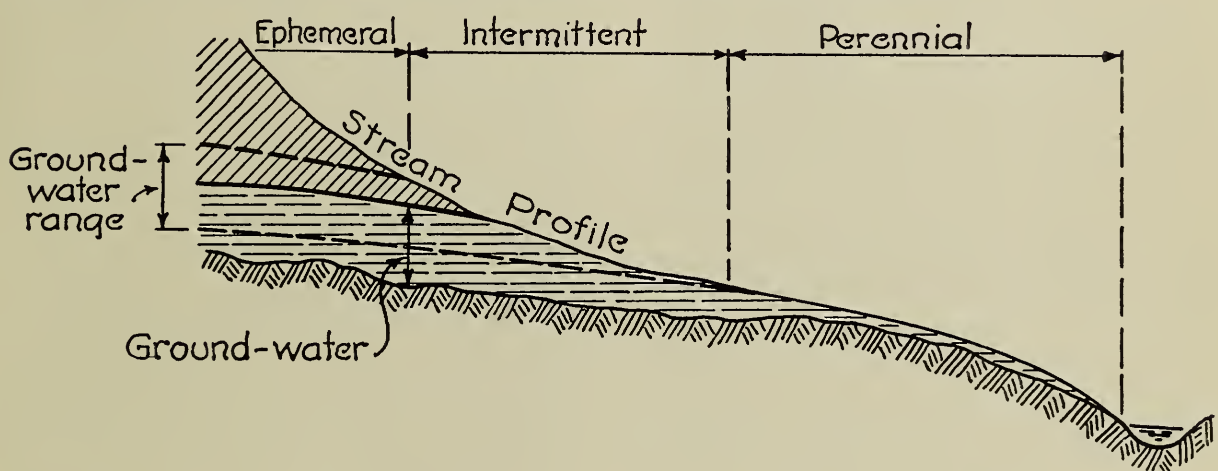


BELTS OF EPHEMERAL (A) AND INTERMITTENT (B) STREAMS AT THE HEADWATERS OF A DRAINAGE BASIN. (SCHEMATIC)

FIGURE 2.

streams (fig. 2) and it is only at some distance from the heads of the tributaries that streams become perennial. A stream can be perennial, because and only because it is supplied by

ground water or other storage which maintains its flow during intervals between rains. Proceeding upstream, stream channel profiles usually rise faster than the ground-water table (fig. 3). When the stream channel rises above the water table the stream becomes intermittent or ephemeral. Ephemeral streams in a state of nature are of little use to the lands to which they lie adjacent. The width of the ephemeral belt around a drainage basin differs from year to year, being greatest in dry, least in wet, years. One of the things which may apparently be accomplished to some extent by surface run-off control is permanent reduction in the width of the ephemeral belt of drainage basins. Reference has been made to this matter in advance of general discussion of the subject (1) because this distinction between headwater streams and those in the interior or lower portions of drainage basins has not generally been recognized, (2) because it serves to show one of the intimate connections between surface run-off control and upstream engineering.



GROUND-WATER CONDITIONS – HEADWATER STREAMS

FIGURE 3.

Surface run-off control is an attempt to modify the hydrologic cycle comprising the ever-recurring sequence of rainfall, run-off, and evaporation. To a limited extent surface run-off control has been accomplished from time immemorial by terracing and similar means and to some extent it occurs incidentally, with either beneficial or deleterious effects, in all field practice in agriculture. Attempts to understand the processes involved and to practice surface run-off control along the lines of scientific principles are relatively new—in fact, the understanding of the processes is neither complete nor widespread at the present time and much that is given in this paper is based on researches in progress and results so new that they have not hitherto appeared in print. Some revision of statements made herein is likely to be required as knowledge of the subject advances.

It may be assumed without discussion that it is impracticable to increase local rainfall to a material degree. So much of the rainfall as exceeds the run-off to the oceans is derived through evaporative processes from the land. Agricultural practices which increase evaporation must increase rainfall somewhere. Over land areas the principal source of evaporation is that which takes place as transpiration through vegetation. Most persons do not realize the amount of energy required to evaporate water. The source of the energy is solar radiation. Except as it may result from increased transpiration there does not appear to be any practicable

way of materially increasing evaporation. Furthermore, increased direct evaporation from the soil would be deleterious rather than beneficial. Also, any large increase of evaporation would result in lower temperatures.

Run-off in the ordinary sense is the difference between rainfall and evaporation and so considered it appears that, since neither rainfall nor evaporation can be practically controlled, the amount of total run-off is also largely beyond human control and is affected relatively little either by methods of cultivation or by the type of plant cover on the ground surface.

There is another concept of run-off, i. e., that it is the sum of surface run-off and ground-water flow. This more recent viewpoint offers a more helpful outlook since any decrease of surface run-off means of necessity a corresponding increase in the amount of water that enters the soil, to be disposed of either as transpiration or ground-water flow. Conversely, any procedure that results in an increase in the amount of rain entering the soil as infiltration results of necessity in a decrease of surface run-off.

Several beneficial results may follow surface run-off control:

1. Reduction in soil surface erosion and gullying of the soil, with consequent reduction in the silt transport of rivers and the sedimentation of reservoirs.

2. Increase in the soil moisture available for vegetation.

3. Increase of the ground-water storage, either through raising of ground-water levels or their equalization, thus providing an increase of ground-water flow of streams and better sustained ground-water levels for domestic or other uses and for the supply of such types of vegetation as depend in part upon the water table.

4. A decrease in flood intensity in ordinary floods, although, as pointed out later, there may be little if any decrease in maximum flood intensities. There will, however, be a substantial decrease in the frequency of occurrence of floods.

5. A general betterment in the regularity or regimen of streams, particularly headwater streams and first order tributaries, providing perennial flow where only ephemeral flow previously existed.

These are the objectives of surface run-off control. They all come under the head of conservation of natural resources.

Surface run-off control can be accomplished through various operations which modify the effects of some of the factors which control surface run-off.

As a practical matter, surface run-off control can be accomplished mainly through operations on the soil surface. This involves something more than is involved in ordinary agricultural practice, and while the main objective is improvement in agriculture, other benefits may follow—for example, improved regulation or better regimen of streams would be highly beneficial in relation to power development. The practical phase of the subject may perhaps more properly be described as "soil-surface engineering" rather than "upstream engineering." Much is yet to be learned about the practical methods by which surface run-off control can best be accomplished, particularly as these methods must in general be compatible with and fit in with agricultural practice, and no attempt will be made to present a full discussion of this phase of the subject. It is quite as important to know the limitations as to know the possibilities of attainment of new methods in applied science, and some attention will be given to the question of practical methods of surface run-off control from this viewpoint.

Hitherto the study of run-off has been mainly experimental, and only empirical or statistical relations have been determined. It is easy to get together a small graveyard full of formulas developed to express run-off in terms of rainfall and other factors, all of which formulas have been weighed and found wanting, for the reason that none of them includes all of the independent variables which govern surface run-off nor does any

one of them involve the correct relationships between these variables.

The only certain, sound basis for soil-surface engineering is a rational understanding of the processes involved in surface run-off, the factors or variables that control these processes, and the relations between them. The primary purpose of this paper is to outline briefly the manner in which surface run-off takes place.

THE INFILTRATION THEORY OF SURFACE RUN-OFF

As a basis for further discussion it is necessary to devote a little time to what may be called the infiltration theory of surface run-off, as developed by the author within the past few years.[1] [2] This theory is predicated primarily on the simple proposition that total surface run-off in any storm equals the total rainfall minus total infiltration. It also involves the following facts of observation:

1. That unless the rain intensity exceeds the infiltration capacity of the soil (f), no surface run-off occurs.
2. That when the rain intensity exceeds the infiltration capacity, the excess rain at first accumulates on the soil surface, filling the small depressions which exist on all soil surfaces, natural or cultivated, if not too steep.
3. When these depressions are filled and overflow, the surface water standing on the ground surface as temporary storage or surface detention passes as overland flow toward the stream channel.
4. That the rate of surface run-off at any moment is a simple function of the average depth of surface detention along the stream margin.
5. That the rate of surface run-off and the total run-off are controlled by the storage equation:

$$\text{Inflow} = \text{outflow} + \text{gain of storage}$$

the storage in this case being surface detention.

A better understanding of the processes is obtained by examining a rain intensity graph or phreatograph in conjunction with the run-off graph which it produces. For this purpose one of the excellent series of run-off experiments conducted by W. W. Horner and H. T. Flynt on small drainage basins at St. Louis has been utilized (fig. 4).

This drainage basin has an area of 4.34 acres. At the time of this storm, September 7, 1916, the average infiltration capacity of this drainage basin was 0.58 inch per hour.

Referring to figure 4, there was first an interval in which the rain intensity was just about equal to the infiltration capacity. Such a period at the start of a storm, in which the rain intensity does not exceed the infiltration capacity, nearly always occurs and is designated the *initial rain interval.* The part of the storm duration during which the rain intensity exceeds the infiltration capacity is designated the *rainfall excess interval.*

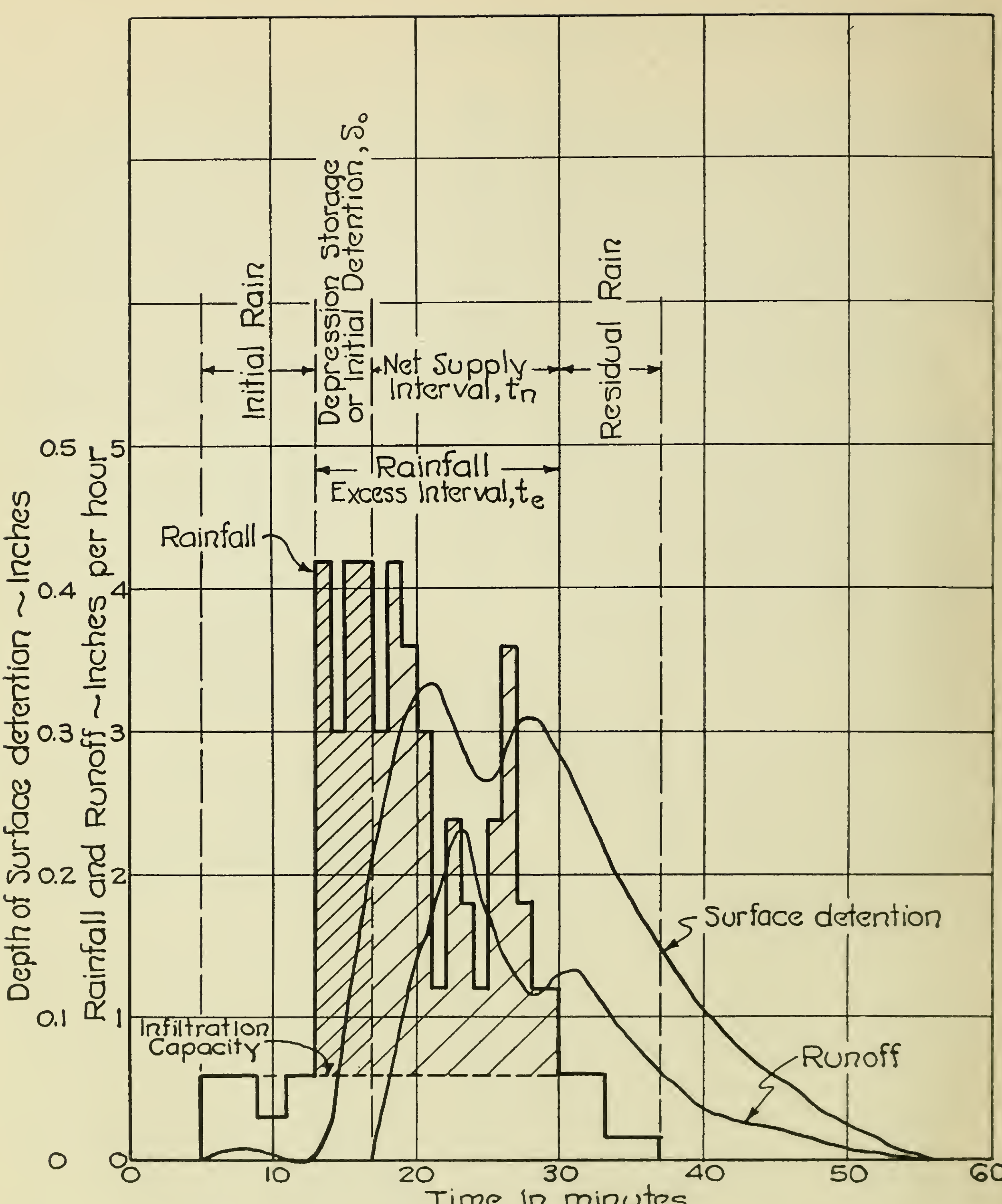
During the initial rain interval, infiltration takes place at a rate equal to the rain intensity. No surface run-off occurs. Each raindrop is absorbed when and where it falls on the ground. During the rainfall excess interval, infiltration takes place at a rate equal to the infiltration capacity of the soil.

It will be noted that run-off did not begin until after rainfall excess had persisted for several minutes. This interval, which is the time required for rainfall excess to fill up the depressions in the soil surface, is designated the *depression storage* or *initial detention interval.* Finally, there is nearly always rain at the end of the storm at intensities less than infiltration capacity. This is designated *residual rainfall.*

The shaded portions of the diagram represent the *rainfall excess* over infiltration. The singly shaded portion represents the net rainfall excess after surface depressions are filled. The doubly shaded portion shows the part of the rainfall

[1] Horton, Robert E. The Role of Infiltration in the Hydrologic Cycle, *Trans. Am. Geoph. Union, 1933,* pp. 446–460.

[2] Horton, Robert E. *Surface Run-off Phenomena, Pt. I: Analysis of the Hydrograph,* Publ. 101, Horton Hydrologic Laboratory; Edwards Bros., Inc., Ann Arbor, Mich., 1935.



RELATION OF RAINFALL TO SURFACE RUNOFF,
EWING AND WASHINGTON BLOCK, ST. LOUIS, SEPT. 7, 1916

FIGURE 4.

excess required to fill surface depressions.[3] The line on figure 4 marked "surface detention" represents the average depth of water on the ground surface at any given time, including depression storage. In the example shown on figure 4 the surface detention attained a maximum of one-third inch on the entire drainage area. The total rainfall was 0.89 inch and the total run-off 0.50 inch. The maximum rain intensity was 4.3 inches per hour, the maximum surface run-off intensity 2.4 inches per hour. Had there been no surface detention, the maximum run-off intensity would necessarily have equalled the maximum rain intensity minus the infiltration capacity, or 3.7 inches per hour. When rainfall excess ended there still remained on the ground, in this instance, nearly 0.3 inch depth of water as surface detention. This, together with residual rainfall, was in part disposed of as surface run-off, in part absorbed by infiltration. When rainfall excess ends, the water flows off from the ground surface or is absorbed by infiltration, first near the divide, then proceeding down the slope toward the stream channel, until, finally, surface run-off ends when the surface detention, exclusive of depression storage, becomes zero along the margin of the stream channel. It may be noted in passing that whereas initial rain produces no surface run-off, a considerable portion of residual rain of equal intensity and duration would be contributed to surface run-off.

While there are large variations in their relative magnitudes and importance, the different phenomena of surface run-off follow the same sequence and are essentially the same for all rains of a given duration that exceed the infiltration capacity, for all types of soil, from sand to heavy clay, for all initial conditions of the soil surface, whether newly plowed or cultivated, wet, rain packed or dry and sun checked, and for all types of soil cover, bare or with row crops, such as corn or cotton, or covered with close grains, grass or forests.

The maximum run-off intensity always occurs at or before the end of the rainfall excess interval. Since the maximum run-off and—except where there is residual rain—the total surface run-off, are produced solely by rain which falls at intensities exceeding the infiltration capacity; that is to say, during the rainfall excess interval, it is convenient to call the difference between rain intensity and infiltration capacity the supply rate (σ) and the accumulated difference, the supply.

It seems evident from this illustration that infiltration capacity and surface detention are the most important factors controlling surface run-off and that the possibilities of soil surface engineering or control of the surface phase of the hydrologic cycle rest primarily on one of two things: Either increasing the amount of surface detention or increasing the amount of infiltration. An increase of the amount of surface detention increases the infiltration by prolonging its duration. It has also other beneficial effects.

Some of the processes outlined will now be followed more in detail.

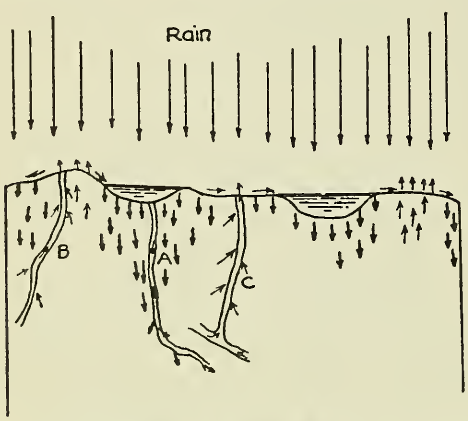
INITIAL DETENTION OR DEPRESSION STORAGE

Suppose a heavy rain is about to occur and you walk over a small drainage basin during the storm. It may be assumed that the land is cultivated, contains no crop, but is prepared for the sowing of fall grain. The soil surface is initially dry and somewhat sun checked. Also, suppose there is a gaging weir on the outlet of the stream. The gentle initial rain is absorbed by the soil, drop by drop. When the rain intensity rises above infiltration capacity you notice that little pools of water begin to form in the small depressions and tillage furrows at your feet, and if you will get down on your knees and look closely you may see a thin film of water creeping down the slopes of the tillage marks and, perhaps also, air

[3] If there is a cover of vegetation, initial detention also includes so much of the interception storage held in suspension on the leaves and stems of plants as is derived from excess rainfall. If there is initial rain, then the interception storage on vegetation is usually derived wholly or mainly therefrom.

bubbles escaping at their summits—for water can only enter the soil as rapidly as the air escapes (fig. 5). The films of moving water that are flowing into the little pools at your feet may not be noticed from a standing position, as they are very thin.

Suppose it has now been raining for half an hour. You go down to the weir and find to your surprise that no surface run-off is taking place, and you realize that the small irregularities and depressions in the soil are of considerable importance in the economy of nature. You



SECTION OF SOIL DURING SURFACE RUNOFF SHOWING ENTRANCE OF WATER (HEAVY ARROWS) AND ESCAPE OF AIR (LIGHT ARROWS).

Figure 5.

make a little computation. It has rained for half an hour at an intensity of 1 inch per hour. You know that the infiltration capacity of the soil is one-half inch per hour. Since no run-off has occurred, it is evident that in this case the depressions in the soil surface are capable of holding the equivalent of one-fourth inch depth of rain over the entire drainage basin and preventing the occurrence of surface run-off until the rainfall has exceeded one-half inch. Undrained depressions, such as are shown on figure 5, exist on every soil surface not too steep, whether natural or cultivated. For the most part they are barely noticeable and hitherto you have thought of this underfoot water during rain as something of a nuisance, making for sloppy walking and wet feet. While they drain out on steep slopes, or moderate or gentle slopes, they can commonly hold the equivalent of one-fourth to one-half inch depth of water and even more in natural meadow and forest land. Cultivation tends to destroy the natural depressions, but to a considerable extent replaces them by tillage marks. The water in these depressions is held until after rain ends and is then mostly absorbed by infiltration. The process is repeated in every rain of sufficient duration and intensity to fill the depressions, and so in the course of a summer several inches of water may be added to the soil. Nature takes this toll before permitting any surface run-off to occur. In addition to increasing the total infiltration, surface depressions in effect reduce the duration of surface run-off by a length of time equal to that required to fill the depressions. The time required to fill depressions is equal to their capacity divided by the rainfall excess rate. In the example cited it is one-half hour, so that a 2-hour storm on such an area is reduced to the equivalent of a 1½-hour storm as far as intensity and volume of surface run-off are concerned. The effect of surface depressions in increasing infiltration is the same in long as in short rains, but their effect in decreasing run-off intensity becomes negligible if the rain lasts long enough so that the run-off intensity becomes substantially equal to the supply rate. It is evident that natural storage of water on the ground surface during rain is an important means of reducing surface run-off intensity. Unfortunately, natural surface depressions, while highly effective on flat lands, diminish rapidly in volume and effectiveness as the surface slope increases, and it is on the steeper slopes that they are most needed.

OVERLAND FLOW

If, again, you will go out in the fields during rain, after the depressions are filled, and get down on your knees so you can observe closely, you will find that practically the entire ground surface is covered with running water. There are thin, barely perceptible films moving down-

ward from the higher spots, with water an inch or two deep in the little valleys and depressions. This also is moving but more slowly. You notice the great variation in depth and velocity of overland flow even at closely adjacent points and you wonder if there is any law excepting the law of chance that governs the phenomena of overland flow and surface run-off. Since surface detention is of the nature of storage, it is governed by the law of storage. This is as fundamental as the law of gravitation and applies to the storage of anything whatever—corn in the granaries of Egypt, electricity in a storage battery, or water in a stream. Expressed concisely, this law states that, in any given time—Rate of outflow = Rate of inflow − Rate of gain of storage. As long as storage is increasing, outflow must be less than inflow, whether the storage is in a great reservoir or merely as surface detention on an acre of ground. You know that if you multiply all of the terms of an equation by the same quantity the equation is not changed. So it comes about that the storage of water during rain as surface detention of a few thousand cubic feet of water on each acre of ground in a drainage basin will accomplish as great a result in flood reduction as the storage of many billions of cubic feet in a large reservoir on the main river.

Mixed and confusing as it appears on the ground surface, overland flow is always some type of hydraulic flow. It is either turbulent or laminar, or a mixture of turbulent and laminar flow. If the water is clear and not moving too swiftly, the flow which you see is probably of the type known as laminar or nonturbulent; it is slow and smooth, like the flow of molasses; it contains no eddies, and while it can push or roll soil grains, even uphill, it cannot carry them in suspension—only turbulent flow can do that. If all direct surface run-off was of the nonturbulent type, there would be but little erosion of the soil surface. Unfortunately laminar flow can exist only with very shallow depth and flat slopes—for example, water flowing at a depth of a quarter of an inch and a velocity of one foot a second is nearly always turbulent. Its erosive power is enormously increased as compared with laminar flow.

Aquatic grass in a stream is a most effective means of producing eddies and converting laminar into turbulent flow. It seems strange that a grass-covered soil surface should be so effective as it is known to be in reducing run-off and preventing soil erosion. This matter will be taken up later. If the surface detention line has been drawn on a graph of surface run-off, such as figure 4, it is easy to determine the laws governing both the velocity and volume of overland flow or surface run-off.[4] Plotting the rates of surface run-off in terms of depth of surface detention on logarithmic paper you will usually find, if the data are good, that the plotted points fall close to a straight line. This means that the law governing the rate of surface run-off in terms of the depth of surface detention is a simple power function.

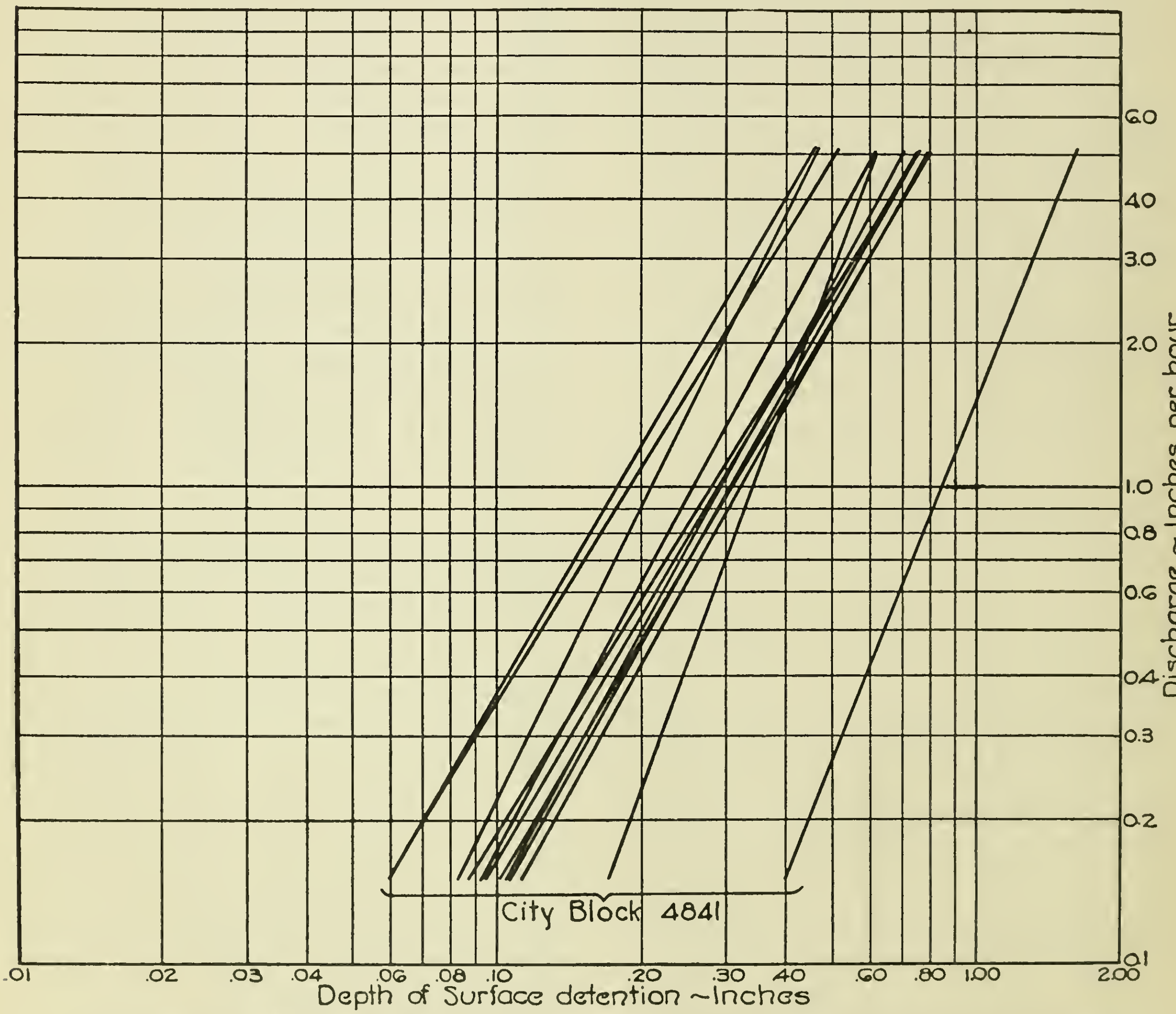
Figure 6 shows the logarithmic lines representing the relation of surface detention depth to run-off intensity for several storms on one of Horner and Flynt's experimental areas at St. Louis. The slopes of the lines determine the exponent in the power function. The slopes are quite uniform, indicating nearly the same degree of turbulence in all cases, and the average exponent is about 2, indicating that the flow is mostly turbulent on this area.[5] There is considerable variation in the coefficients, which are indicated by the abscissas on the diagram. This variation is

[4] The ordinate of the surface detention line on a hydrograph for any given time is obtained by subtracting the ordinate of the mass run-off graph from that of the mass line of rainfall excess, or—Detention = Mass rainfall − (Mass infiltration + Mass run-off).

[5] Lewis and Neal, The Flow of Water in Thin Sheets, *Trans. Am. Geoph. Union, 1935*, pp. 454–456, also indicate that overland flow over bare soil is usually turbulent or mostly turbulent, except perhaps close to the watershed line. Mixed flow, i. e., part turbulent and part laminar, means that at a given section across which surface run-off is taking place, the flow is turbulent in some places, laminar in others.

largely due to the fact that the rain intensity was not uniform over the entire drainage basin during most of these storms.

To avoid confusion the points from which these lines were plotted have been omitted. Except for slight depths where the flow becomes laminar, the points fall close to the lines. This is a city area with some roof and pavement and smooth surfaces, with little depression storage. The lines on figure 6 are plotted in terms of total detention, including whatever depression storage there is.



RELATION BETWEEN SURFACE DETENTION AND SURFACE RUNOFF INTENSITY, ST. LOUIS EXPERIMENTS BY W.W. HORNER

FIGURE 6.

VARIABLES CONTROLLING SURFACE RUN-OFF

The factors or variables governing overland flow are the same as those governing ordinary hydraulic flow of the same type. For turbulent flow these are: Depth of water, slope and roughness of the surface. The depth of overland flow

at a given time and at a given point in a drainage basin is governed by the length of overland flow and by rain intensity, infiltration capacity, and initial detention. It is, therefore, possible to write down a list of all the variables involved in surface run-off. They are:

1. Rain intensity during rainfall excess.
2. Infiltration capacity.
3. Volume of depression storage.
4. Rainfall excess duration.
5. Length of overland flow.
6. Slope of surface.
7. Surface roughness coefficient.

These seven variables control all the phenomena of surface run-off until the maximum run-off occurs and until rainfall excess ends.

To determine the total run-off it is necessary to add to these the rain intensity during the residual run-off interval. Knowing the variables, the law of surface run-off, and the storage equation, it is possible to treat the subject of surface run-off phenomena analytically and to establish precisely and certainly the relationships between the different variables for a given type of overland flow. Such analyses of run-off phenomena have been made by the author for various types of overland flow but it is impracticable to give them here. It is also possible to undertake the synthesis of a run-off graph, i. e., to determine with considerable certainty and accuracy the run-off graph that would be produced under a given set of prescribed conditions. Such hypothetical surface run-off graphs serve well to show the effect of change in any one of the controlling variables, and will here be used for that purpose. The graphs used are, for the sake of simplicity, predicated on uniform rain intensity, with neither initial nor residual rain, and on rectangular areas.[6]

Any method of modification of the surface phase of the hydrologic cycle operates through changing one or more of the seven variables listed above. Rain intensity and duration cannot, of course, be changed. Only the effect of such changes in these variables as are involved in terracing or are related to the controlling effect of sod on run-off will be considered here.

TERRACING

It is my purpose to discuss hydraulic and hydrologic principles which should guide in the design rather than to discuss details of design of terrace systems. To bring out clearly these principles two types of terracing will be considered.

1. *Sloped bench terrace.* As constructed in semiarid regions, bench terraces are usually level, both crosswise and lengthwise. Such terraces may not be practicable on friable soils in humid regions, where the accumulation of heavy rains on the ground surface may cause erosion or destroy crops.

For the purpose of discussing effect of length of overland flow and slope of surface, a modified form of bench terrace will be considered, with benches level in the direction of the dip of the slope but with a slight gradient along the strike of the slope. The length of the benches will generally be limited by the distance between gullies on the slope, and the length of overland flow may be either greater or less than the original length of the hillside.

2. *The ordinary Mangum terrace.* The Mangum terrace is cheaper to construct and involves little disturbance of the natural topsoil. Except on relatively flat slopes, where it is least needed, level terracing involves, in general, costly regrading of the entire hill slope

[6] The graphs used in this paper are computed for 75 percent turbulent flow, or with the exponent $M=2.0$ in the run-off equation $q_s=K_s \delta^M$, where q_s is the rate of surface run-off, δ the average depth of surface detention along the stream margin, and K_s depends on the slope, roughness, and length of the surface from which run-off takes place. Various amounts of residual rainfall have been allowed for on different graphs, as indicated thereon. These hypothetical graphs have more sharply defined crests than surface run-off graphs for most natural areas. This is because they are predicated on rectangular areas, whereas most natural drainage basins are irregular in form, as a result of which the surface run-off graphs are more rounded.

and consequent disturbance or removal of the natural topsoil. In passing it may be remarked that the statement has sometimes been made that the topsoil, once removed, can never be replaced. This is probably true for some areas with shallow indigenous soils where there is a rapid change from the mature fertile topsoil to the underlying parent rock. It is not true for deeper transported glacial and alluvial soils—in fact, the practice of subsoiling, that is, plowing deep every few years so as to bring up new soil material, has been common for generations. Furthermore, if the subsoil contains sufficient fine material, newly exposed surfaces in road cuts or elsewhere often quickly develop a succession of vegetation, sometimes starting with sweetclover, where lime is present, so that in the course of a few years the new land will produce crops and can barely be distinguished from the older adjacent soil. Obviously, in such lands, level terracing will not destroy the productivity of the soil.

The principal distinction between the two types of terracing is that in case of the Mangum terrace the length of overland flow is reduced from the natural length of the hill slope to a distance somewhat less than that between the center lines of parallel terraces, and the surface slope is not materially changed. Drain ditches are provided behind the terrace embankment. For the type of level terracing here considered there is no drain ditch behind the terrace embankment, but the water proceeds as sheet flow, parallel with the terrace, the surface slope is decreased from that of the natural hillside to that of the terrace surface, and the length of overland flow equals the length of the terrace.

RELATION OF LENGTH OF OVERLAND FLOW TO SURFACE RUN-OFF

Working at the North Carolina Experiment Station, F. C. Bartel found that the total surface run-off apparently decreased as the length of the experimental plats increased, other things equal. This result attracted considerable attention as there was no reason superficially obvious why it should be true. It has, however, been verified by several other investigators,[7 8 9] including Musgrave, who made a study of all the data.

Figure 7 shows surface run-off graphs for a 4-hour storm, with rain intensity of 0.8 inch per hour, on areas identical in every respect excepting length of overland flow, and all with infiltration capacity of 0.4 inch per hour. The scale at the left gives the run-off intensity q_s in inches per hour. It will be noted that for lengths l_0 of 50 feet and 100 feet, the run-off intensity had attained the maximum possible, namely, 0.4 inch per hour, at the end of 4 hours and was the same in these two cases. For longer areas the maximum run-off intensity had not been attained at the end of 4 hours and the intensity at the end of the 4-hour storm decreased materially as the length of overland flow increased. If the length of the storm had been much greater, namely, 8 to 12 hours, the run-off rate would have equaled the difference between rain intensity and infiltration for all lengths of overland flow and all would have given the same maximum run-off rate. This shows that in short storms the maximum run-off intensity decreases as the length of overland flow increases but in prolonged storms, such as usually produce maximum floods, length of overland flow may have little effect on the maximum run-off intensity attained.

Since the area under any one of the surface run-off graphs represents the total surface run-off it is evident that for 4-hour storms the total run-off decreased as the length of overland flow increased, and since the portion of the graph shown on the diagram would remain the same if the storm had continued longer than 4 hours,

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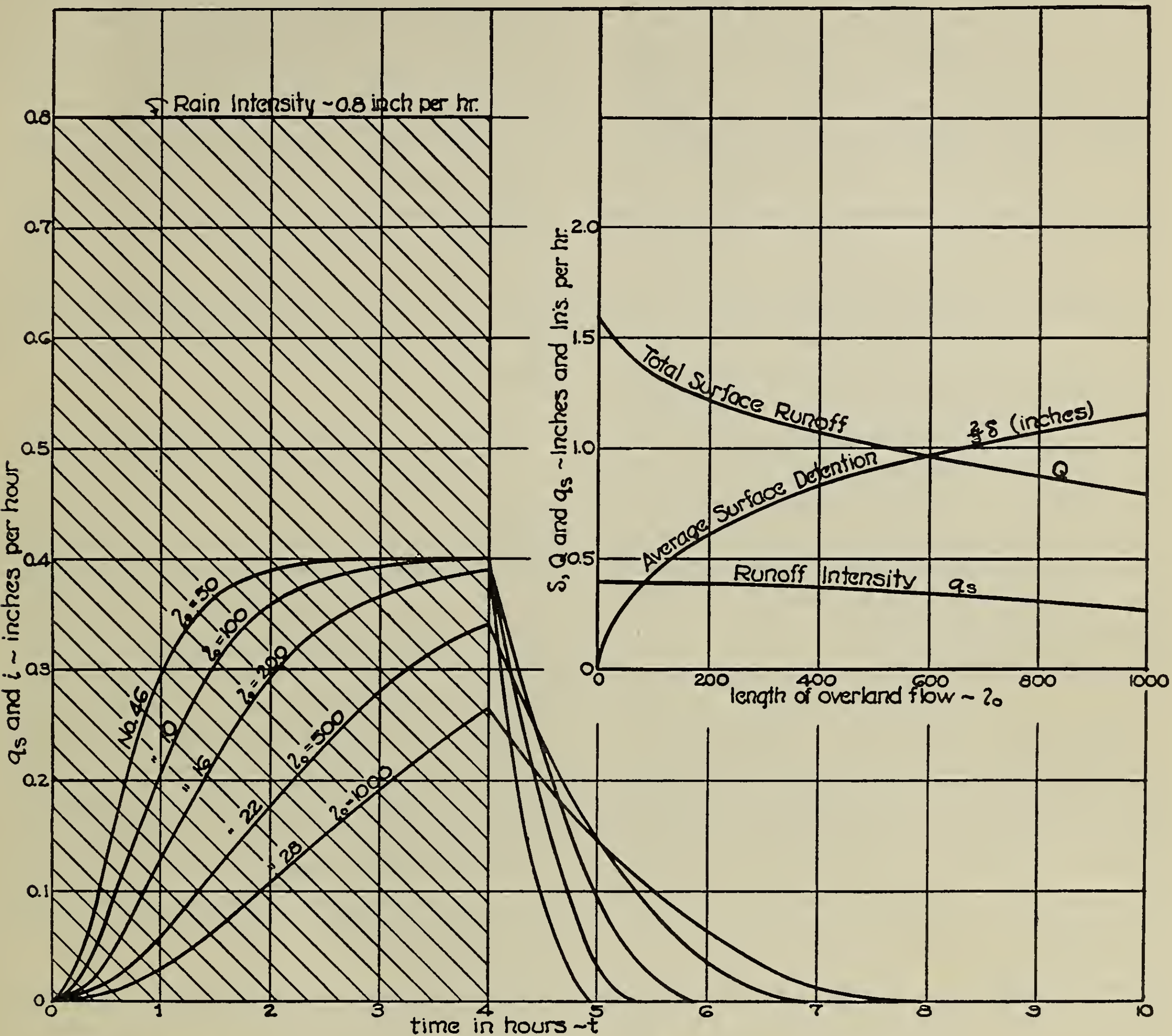
[7] Duley and Ackerman, Run-off and Erosion from Plots of Different Lengths, *Journ. Agric. Res.*, Mar. 15, 1934, pp. 504–509.

[8] Bennett, H. H., Dynamic Action of Rains in Relation to Erosion in the Humid Region, *Trans. Am. Geoph. Union, 1934*, pp. 474–488.

[9] Musgrave, G. W., Some Relationships Between Slope-Length, Surface Run-off and the Silt Load of Surface Run-off, *Trans. Am. Geoph. Union, 1934*, pp. 472–478.

it is evident that there is a decrease in total run-off as length of overland flow increases in case of all lengths of storm.

4-hour storm on the areas of different lengths. As the length of overland flow increases, the surface detention depth increases. Aside from



EFFECT OF LENGTH (l_o) OF OVERLAND FLOW ON SURFACE RUNOFF INTENSITY

Rain Intensity = 0.8 inch per hour for 4 hours
Infiltration Capacity = 0.4 inch per hour
Recession graphs computed for residual rain intensity of 0.15 i.p.h.

FIGURE 7.

The reason for this decrease in run-off with length of overland flow is revealed by the inset diagram on figure 7, which shows the average depth of surface detention at the end of the residual run-off after rain ends, the total run-off equals the supply during rainfall excess minus the surface detention, so that, other things equal, an increase in surface detention invariably

brings about a decrease in total surface run-off. The relation of total surface run-off to length of overland flow, for the cases shown by figure 7, is given by the total surface run-off line on the insert. In these cases an increase in the length of overland flow from 50 to 1,000 feet reduced the total surface run-off about one-half but reduced the maximum run-off intensity by only about one-third. The total surface run-off curve on figure 7 closely resembles similar curves obtained from field plat experiments. It is evident that subdividing a slope into segments, as in the application of Mangum terraces, tends to increase the maximum surface run-off intensity in shorter storms and increases the total surface run-off in all storms. These effects may be offset by the increased storage in the drainage ditch behind the terrace. If, therefore, a decrease of surface run-off and an increase of infiltration are to result from the use of terraces of the Mangum type it must be brought about through a still larger increase of infiltration from the drain ditch.

EFFECT OF SLOPE ON SURFACE RUN-OFF

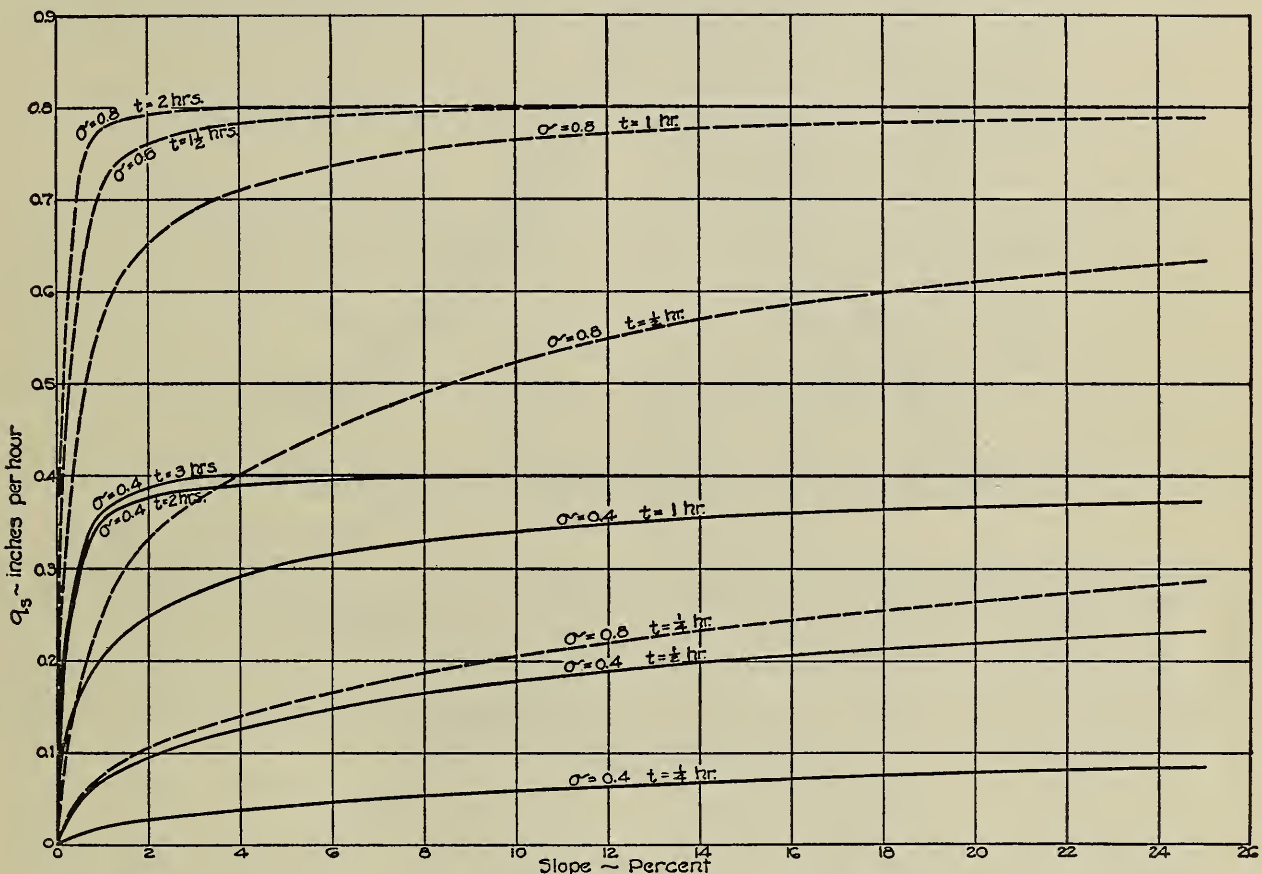
A decrease of surface slope affects both the run-off intensity and total run-off in much the same way that these quantities are affected by increase of length of overland flow, as shown on figure 7. In order to bring out the difference in the effects of change in slope in long and short storms, curves have been prepared, figure 8, showing run-off intensity for storms of different durations, with different ground surface slopes. In each case σ is the difference between rain intensity and infiltration capacity and t the duration of rainfall excess, in hours. For storms of one-half hour duration or less, the maximum run-off intensity increases with slope for all slopes; for storms of 1-hour duration the maximum surface run-off intensity increases with slope up to about 15 percent gradient. For steeper slopes the maximum run-off intensity is approximately attained in 1 hour and is not affected by further increase of slope. For storms of 2 to 3 hours' duration the maximum run-off intensity increases rapidly with increased slopes from zero to 2 percent but for steeper slopes, the maximum run-off is nearly independent of the slope, since the limiting intensity is attained for steeper slopes within 2 to 3 hours. There is, however, always some increase in total run-off, other things equal, with increasing slope, and a consequent decrease in infiltration. A modified level terrace will, therefore, owing to decreased surface slope, greatly reduce the run-off intensity in short storms and increase infiltration to the soil in all storms although it may not affect maximum run-off intensity in prolonged storms.

EFFECT OF DEPRESSION STORAGE ON SURFACE RUN-OFF INTENSITY

The full effect of variation in surface slope on run-off intensity, total run-off and infiltration is not revealed by a consideration of the relation of slope alone to these factors. The reason is that on natural areas the volume of depression storage generally decreases as slope increases, becoming negligible for slopes sufficiently steep so that the depressions due to natural irregularities in the soil surface are drained. The full effect of decrease of surface slope, as, for example, by the use of modified level terraces, is the combined effect of decrease in velocity of overland flow and increase of surface detention, and the effect of increased depression storage on the flatter slopes.

As already pointed out, the effect of depression storage is to decrease the effective duration of rainfall excess by an amount equal to the time required to fill the depressions. Figure 9 illustrates three cases: With no depression storage, and with depression storage equivalent to 0.4 inch and 0.8 inch depth on the surface, respectively. It also illustrates the effect for two different conditions. The upper diagram relates to the run-off from a storm of 4 hours' duration and 1 inch per hour intensity. The lower diagram relates to a storm of 10 hours' duration

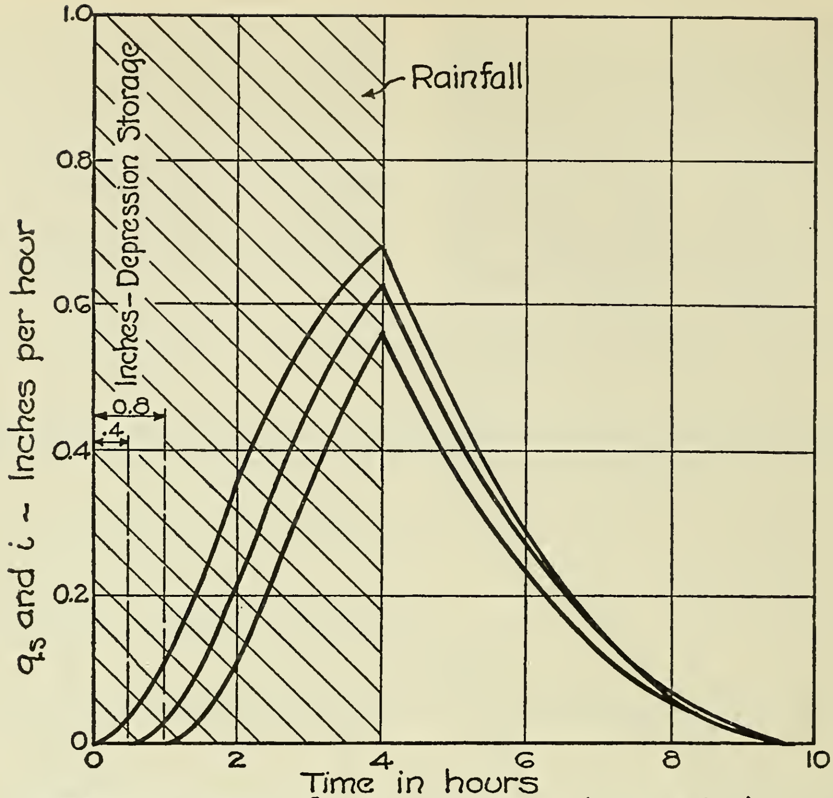
and 0.6 inch per hour intensity, the infiltration capacity in both cases being 0.2 inch per hour, so that the net supply available to produce run-off is 0.8 inch per hour for the 4-hour storm and 0.4 inch per hour for the 10-hour storm. In the case of the 4-hour storm the run-off intensity had not attained its limiting value and the run-off intensity is reduced nearly in before the end of the storm, so that in this case there is no substantial reduction in maximum run-off intensity. There is, however, as before, a reduction in the total run-off and a consequent increase in the total infiltration. Not only does decrease of surface slope provide a highly effective means of decreasing surface run-off and increasing infiltration but it can easily be



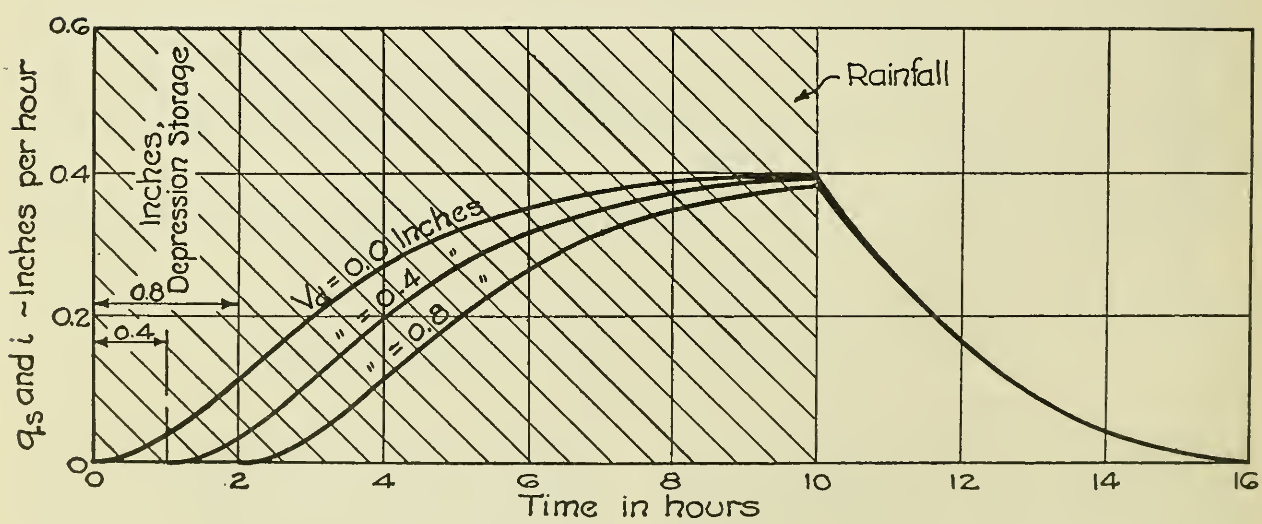
EFFECT OF SLOPE ON SURFACE RUNOFF INTENSITY

FIGURE 8.

proportion to the ratio of the time required to fill depression storage, to the total storm duration. Since the area under each graph represents the total run-off it will also be seen that the total run-off is reduced in about the same ratio. In case of the 10-hour storm the run-off had attained approximately the limiting intensity of 0.4 inch per hour, equal to the supply rate, combined with artificial methods to increase depression storage, as, for example, by the construction of water pockets, thus providing depression storage in excess of that afforded by nature or by customary agricultural practice. To a limited extent this has been done from time immemorial, as by the building of low banks of earth enclosing water pockets around olive



Case 26, $K_s = 0.09$; $f = 0.2-$, $\sigma = 0.8-$, $i_r = 0.03$ i.p.h.



EFFECT OF DEPRESSION STORAGE ON SURFACE RUNOFF INTENSITY

Case 28, $K_s = 0.09$; $f = 0.2-$, $\sigma = 0.4-$, $i_r = 0.05$ i.p.h.

Figure 9.

trees in Arabia.[10] An equivalent of water pockets is extensively used in orchard irrigation. On wet soils much the same thing is accomplished for the opposite purpose—drainage—by ridge-and-furrow cultivation. The possibility of devising some system of farm practice which will divide the soil surface in humid and semihumid regions into small undrained compartments seems worth considering. This would be limited to lands which are not too steep.

RELATION OF INFILTRATION CAPACITY TO SURFACE RUN-OFF

The importance of infiltration as a factor in soil surface engineering can hardly be overestimated. Yet, strange as it may seem, until the publication of a paper in the Transactions of the American Geophysical Union 3 years ago, one would search in vain for published discussions dealing exclusively or in any way comprehensively with this subject.

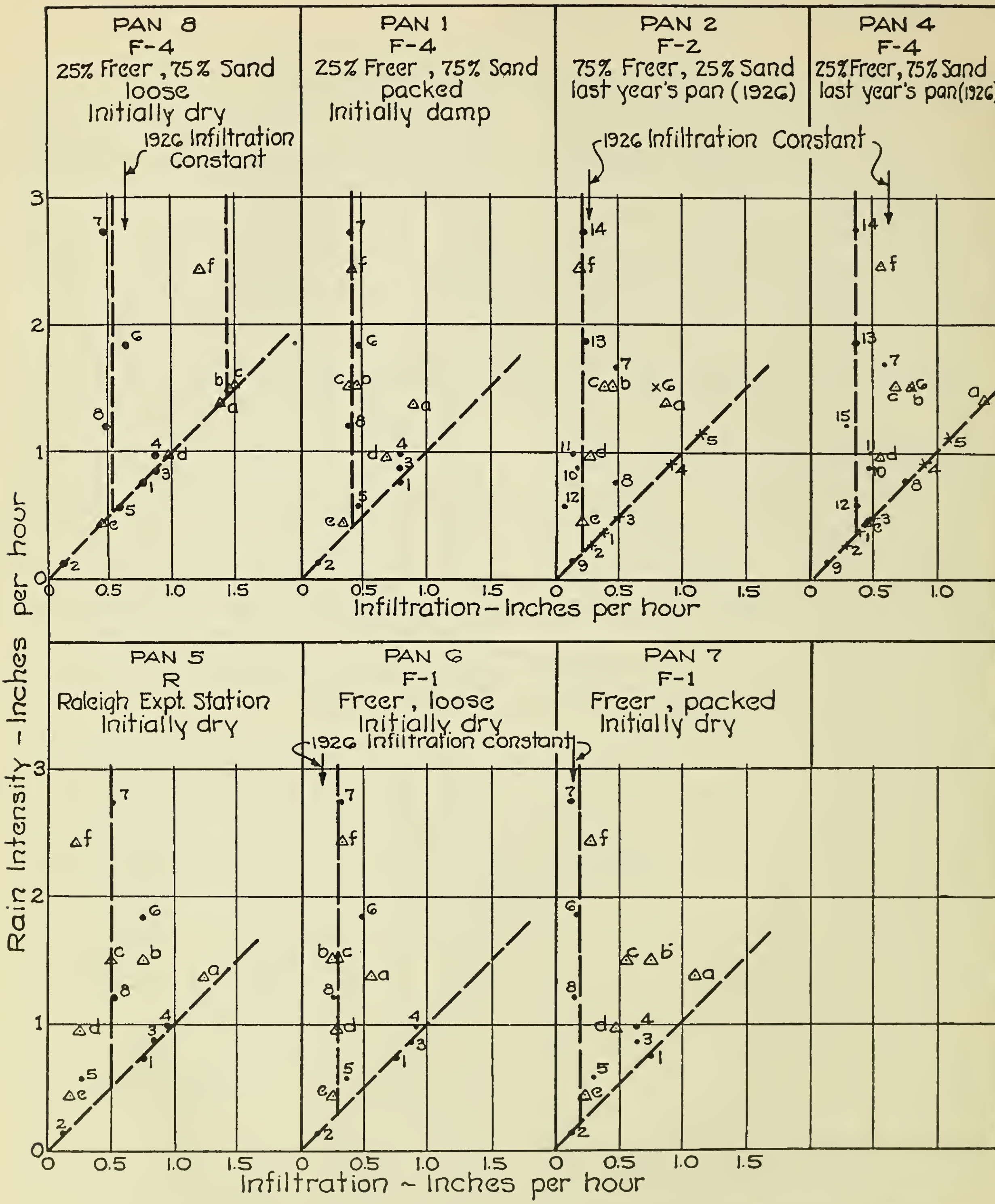
Since higher organisms in the animal kingdom all depend directly or indirectly on vegetation for a living, and higher organisms in the vegetable kingdom all depend on soil moisture to maintain the transpiration stream and supply them with needed minerals, it is evident that without infiltration, rain and sun could not avail to produce any extensive body of living organisms on the earth.

In the preceding discussion it has been assumed that the infiltration capacity of the soil remains constant during rain. There is a cyclical variation of infiltration capacity during and following rain and also a minimum infiltration capacity for each soil which is attained after the soil has been wetted for a time.

The existence of a fairly definite minimum infiltration capacity for a given soil is illustrated by figure 10, which shows the results of a few of the many experiments on infiltration capacity which have been carried out at the author's laboratory. In these experiments each soil was placed in a pan, with drains for surface and subsurface run-off. Water was applied at a constant rate by an automatic sprinkling device. Circles and crosses indicate the first series of experiments with each pan. Triangles indicate subsequent experiments after the pan had stood for 10 days. Numbers or letters indicate the sequence of the experiments. Where the plotted values fall on the diagonal equality line, the rate of application of water was less than the infiltration capacity and the water was all absorbed. In each case, after the soil had been wetted for some time, it reached a minimum infiltration capacity, indicated by the vertical dashed line, and in subsequent experiments the plotted points fall on or close to this line regardless of the rate of application of water. This is the minimum infiltration capacity. In most of these experiments the initial rates of application of water were not sufficient to show the maximum infiltration capacity. Experiments performed after the soil was wetted but before it reached its minimum value generally fall between the diagonal and vertical lines.

Consider first a bare, dry soil, baked or compacted, and, in the case of soils containing colloids, with the surface sun-checked. Under these conditions different types of soil, ranging from fine sands to heavy clays, may have initially about the same infiltration capacity (f). In each case, when rain begins, infiltration capacity decreases, although in case of sand containing no colloids, the decrease is relatively slight. In case of loam the infiltration capacity decreases during rain owing to the swelling of colloids and the consequent closing of sun checks and other perforations, and if rain continues long enough the infiltration capacity reaches a minimum value, at which it remains until rain ends. As the soil dries out, its infiltration capacity increases, reaching a maximum usually in the course of 2 or 3 days. For heavy clay soils a similar course is followed but the minimum reached is much lower and may, in fact, be zero or near zero.

[10] Smith, J. Russel, *Tree Crops*, Harcourt, Brace & Co., 1929, pp. 262–266.



EXPERIMENTAL DETERMINATIONS OF MINIMUM INFILTRATION-CAPACITIES OF VARIOUS SOILS, HORTON HYDROLOGIC LABORATORY SERIES B, OCT.-NOV. 1927

• - 5% slope
x - level pan on pans 2 and 4. Numbers give consecutive order of runs.
△ - runs on Nov. 14 after pans had stood for 10 days. Letters give consecutive order of runs.

FIGURE 10.

There is also a variation of infiltration capacity for the same type of soil with different types of surface or cover. If the soil is initially thoroughly wetted by previous rains it will already be at its minimum infiltration capacity, which will continue unchanged to the end of rain, so that a few days after a heavy rainstorm the infiltration capacity will be restored to a normal maximum value much higher than when the rain began.

If the soil was bare, dry, and uncultivated, the infiltration capacity of the surface soil will fall during rain to the same minimum as for the soil initially wetted, and will follow the same course of recovery after rain ends. In this case the initial and final infiltration capacities may be about the same. If the soil was freshly cultivated so that the surface was loose, its initial infiltration capacity may be much higher than in the preceding case, but in this case the capacity will decrease very rapidly at the beginning of rain, because of rain-packing, and thereafter will decrease to the same minimum as before, but upon drying out it will return to the value for packed soil, much less than the initial value.

If the soil is covered with a good grass sod and is initially baked and sun-checked, then the initial infiltration capacity will usually be considerably above that for a bare, dry, baked soil but may be considerably below that for a freshly cultivated soil.

The high infiltration capacity of sodded soils is apparently due partly to the presence of considerable numbers of relatively large openings into the soil surface. Sun checks, openings left by decaying roots, earthworm and other perforations near the surface, are destroyed by cultivation although they may still persist at greater depths. The importance of the presence of these larger openings in providing for the ingress of water and the escape of air is illustrated by a simple hydraulic calculation, which shows that a single earthworm perforation 0.1 inch in diameter will permit as much water to enter the soil, or as much air to escape, as could flow through 1,000,000 interstitial openings between soil grains of a fine sandy soil. Reduction of surface erosion and the consequent prevention of the closing of the larger soil surface openings by inwashing of fine materials is certainly an important factor in preventing the abrupt reduction of infiltration capacity at the beginning of rain which occurs on newly cultivated bare soils as a result of rain packing.

In long rains, infiltration capacity of the subsoil rather than that of the soil surface may become the controlling factor. Much remains to be learned about infiltration through the subsoil below the depth of cultivation. It is certain, however, that the infiltration capacity of the subsoil is much less variable than that of the surface soil, and if the soil profile is homogeneous, the infiltration capacity of the subsoil is usually equal to or greater than the minimum for the surface soil but may be less than the maximum. If the lower soil horizons are more dense than the surface, then, in long rains, the infiltration capacity may be reduced to that of the subsoil, or below the natural minimum of the topsoil.

High infiltration capacity during short rains commonly prevails for all types of soil when initially dry. To be effective in controlling run-off in prolonged rains such as produce maximum floods, a high minimum infiltration capacity is necessary.

It is unfortunate that aside from the natural benefit of sod cover there does not appear to be much that can be done to increase the minimum infiltration capacity of the soil surface, and still less that can be done to increase the infiltration capacity of the subsoil unless, perchance, some means can be found to increase the number and size of the larger openings within the soil body, such as result from the activity of insects, earthworms and the decay of roots. Certainly the American farmer does not want any more insects! It might be possible to breed bigger and better earthworms—in fact, it is reported that in Madagascar, earthworms grow three-fourths of

an inch in diameter and a yard in length.[11] Importation of these would, however, probably delight the followers of Izaak Walton more than it would prove a panacea to the soil.

That infiltration capacity is the most important factor in controlling surface run-off phenomena is well illustrated by figure 11. The upper diagram shows surface run-off graphs for a 4-hour rain of 1.1 inches intensity per hour on areas otherwise similar but with different infiltration capacities, as indicated on the various graphs. These infiltration capacities ranged from 0.1 inch per hour to 1 inch per hour. The maximum run-off intensity decreases quite uniformly as infiltration capacity increases and would, of course, become zero if the infiltration capacity equalled the rain intensity, 1.1 inches per hour. There is a corresponding decrease in total run-off, as shown by the respective areas under the different graphs. The relation of maximum run-off intensity and total run-off to infiltration capacity is shown by the lower diagram. Both lines approach zero at a nearly uniform rate as infiltration capacity increases toward equality with rain intensity. It will be noted from the upper diagram that in each instance the run-off intensity closely approached its limiting value, or the supply rate, at the end of 4 hours.

The effect of increased infiltration capacity on surface run-off differs from the effect of the other factors—slope and length of overland flow—in one important respect: an increase of infiltration capacity decreases both surface run-off and total run-off in about the same proportion in long and short rains. Surface run-off intensity cannot exceed the supply rate or difference between rain intensity and infiltration capacity, and since total run-off is nearly proportional to the total supply, it is evident that a change in infiltration capacity produces a change in maximum run-off intensity, total run-off and total infiltration which is in all cases nearly proportional to the change in supply rate.

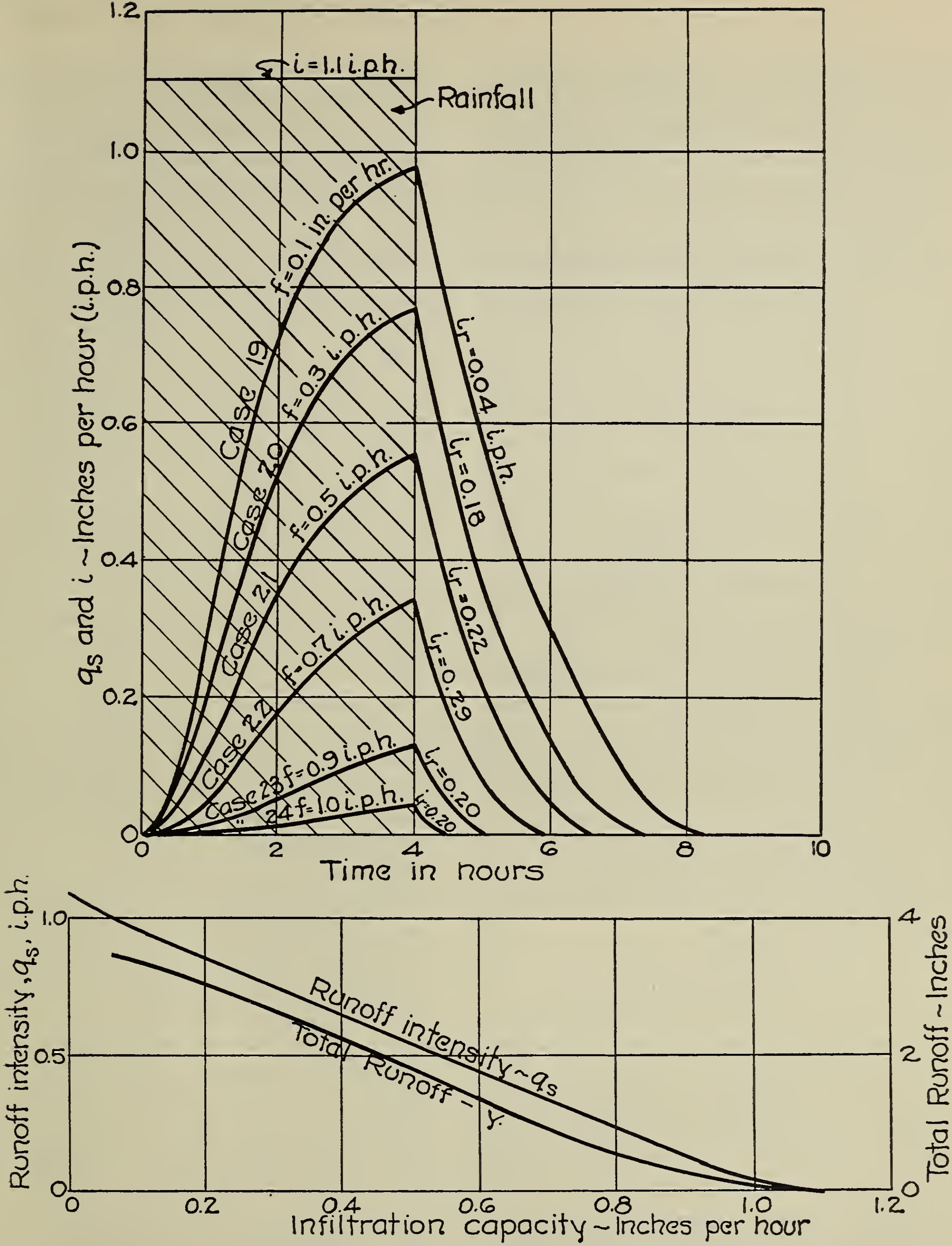
[11] Kellar, C. *Reisenbilder aus Ostafrica und Magagascar*, Leipzig, 1887.

EFFECT OF A COVER OF VEGETATION ON SURFACE RUN-OFF

History repeats itself. Something over 30 years ago President Theodore Roosevelt sponsored a conference here in Washington on the subject of conservation of natural resources. In many respects that conference was similar in its aims and objectives to the one we are now attending although the chief topics discussed were those of conservation of forests and water resources and, among other things, the possibilities of beneficial modification of surface hydrology. It may, therefore, appear to you that there is nothing new in this topic. Since that meeting, in 1905, discussion of the possibilities of modification of the hydrologic cycle through artificial means have been rife and rampant, mainly with respect to the effect of forests on floods and stream flow. Most of the discussions have been predicated on data relative to total run-off from drainage basins and have related to the effect of forests on maximum floods and total run-off. It is fair to say that the discussion has not led to anything conclusive although, unfortunately, incorrect, and misleading statements have found their way even into the high-school textbooks.

Run-off of a perennial stream consists of two parts: surface run-off and ground-water flow. It happens, as already noted, that profound modifications may be brought about in the relative amounts of surface run-off and ground-water flow resulting from ordinary storms without necessarily affecting either the total run-off or the magnitude of maximum floods. Failure to recognize this fact is the principal reason for lack of conclusive results from earlier investigations, particularly with reference to forest hydrology.

It is now well established that a good sod or grass cover is the most effective natural means of controlling surface run-off and preventing soil erosion. The beneficial effect seems to be



EFFECT OF INFILTRATION CAPACITY ON SURFACE RUNOFF INTENSITY

$K_S = 0.18$

FIGURE 11.

more closely related to the density, that is, number of plant stems per unit area, than to the size of the plants. While other things are involved in case of wooded land, the trees of a forest may have less effect in controlling run-off than the grass under the trees.

Reduction of surface erosion by grass cover has often been attributed to the binding effect of grass roots. Kramer and Weaver [12] have shown that the effectiveness of grass cover is more largely due to the aerial parts of the plant than to the roots. The way in which grass cover operates to reduce the intensity and volume of surface run-off does not seem to have been clearly or fully explained. Surface hydrology of grassland and forest differs so much from that of bare soil or soil with wide-spaced row crops that it is difficult to make general comparisons. Broadly it appears that the beneficial effects of a dense grass cover in reducing run-off intensity and volume results mainly from:

1. An increase in surface detention by capillary storage in wedge-shaped spaces between grass leaves or leaves and stems.
2. Better sustained and probably higher infiltration capacity and prevention of closing of openings in the soil surface by inwashing of fine material, as described by Lowdermilk.[13]
3. A different type of overland flow from that prevailing on other soil surfaces. This may be designated "subdivided flow."

SUBDIVIDED FLOW

If a layer of water of uniform depth is flowing over a sloping soil surface it is easy to compute the velocity and volume of flow when the necessary factors are given, by means of the slope formulas of hydraulics, such, for example, as the Manning formula. Friction is taken into account by means of a roughness factor n, which represents the energy lost per unit of surface over which the water flows, and by means of a factor called the hydraulic radius. This is the ratio of area of cross-section of flowing water to the wetted perimeter of the surface or channel over or in which the water flows. For a sheet of water flowing over a broad bare surface the hydraulic radius equals the depth. If the soil is covered with grass the friction surface is greatly increased, although the roughness factor may or may not be changed. The relation of the flow over a bare surface to that over the same surface when grass-covered is much the same as that of the flow over the bare surface to the flow over the same surface if it was subdivided by thin vertical partitions into a large number of narrow channels. The two cases are illustrated by figures 12–A and 12–B. For the bare surface, with fully turbulent flow, the velocity of flow is proportional to the two-thirds power, and the volume of flow to the five-thirds power, of the depth.

For subdivided flow, figure 12–B, for depths not too small relative to the width between partitions, the hydraulic radius is sensibly constant and consequently the velocity of overland flow is sensibly constant, the volume of flow varying directly as the depth.

The condition of nearly a constant velocity for subdivided flow comes near to being something new in hydraulics. Kröber showed experimentally for a somewhat analogous case the existence of constant velocity of turbulent flow through gravel of suitable sizes.[14] The author's attention was directed to this type of flow by the analysis of run-off graphs from LaGrange Brook at Voorheesville, N. Y. This stream drains a sod-covered area of about 40 acres. Further experimentation and the determination of the relation of velocity to depth of overland flow for other sod-covered areas are needed before final conclusions can be reached. It is certain, however, that on

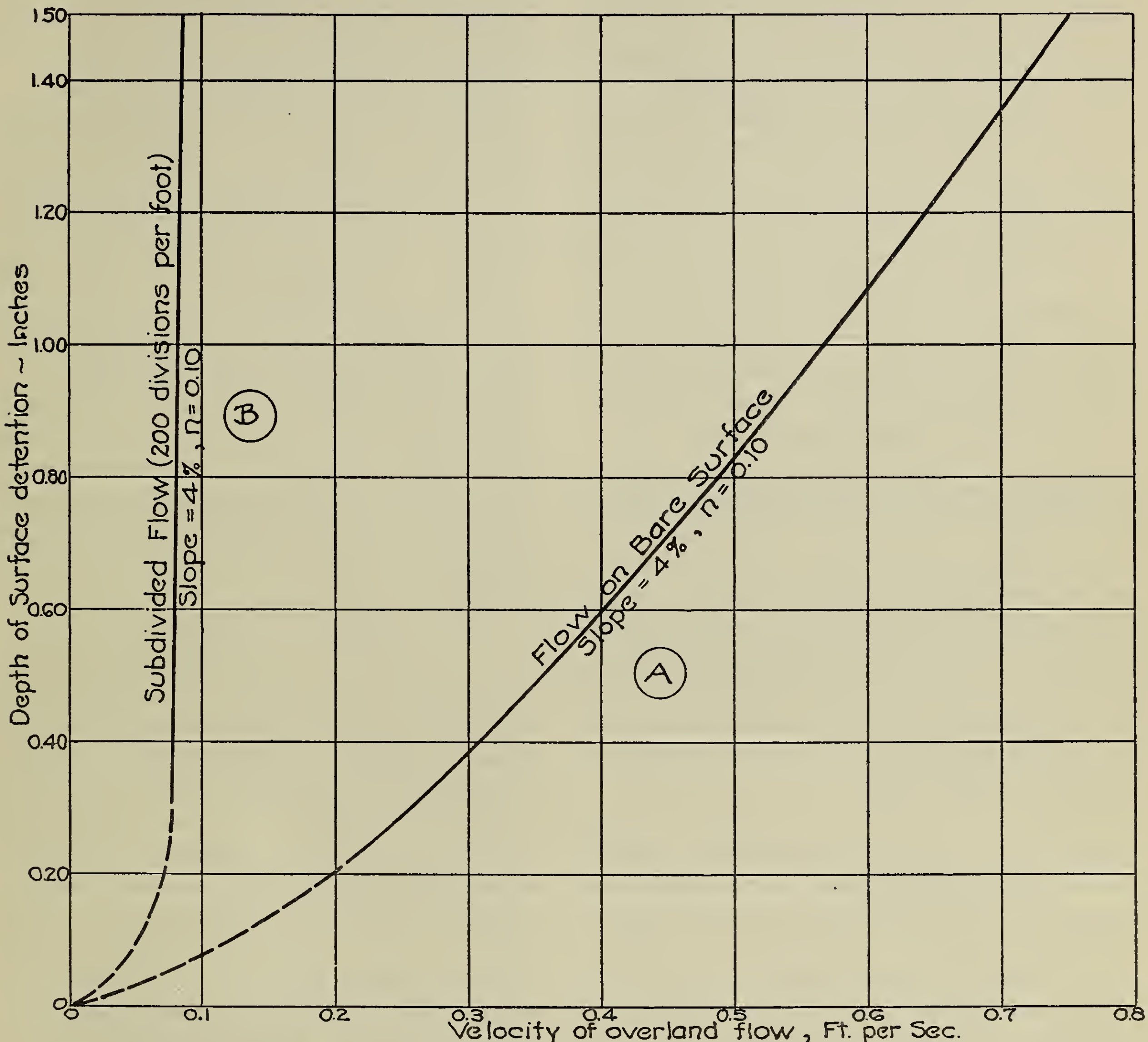
[12] Kramer and Weaver, *Relative Efficiency of Roots and Tops of Plants in Protecting the Soil from Erosion*, Bull. 12, Conservation Dept., Univ. of Nebraska, 1936.

[13] Lowdermilk, W. C., Influence of Forest Litter on Run-off, Percolation and Erosion, *Jour. Forestry*, April 1930, pp. 474–491.

[14] Kröber, B., Researches on the Movement of Water Through Sand Layers (Ger.), *Zeit. d. Deut. Ing.*, 1884, v. 28, p. 593.

grass-covered areas the velocity of overland flow is both lower and more nearly constant than on bare areas with otherwise similar conditions. There are hydraulic reasons for believing that there is a maximum or limiting value of the roughness factor n for a given type of surface and that the roughness factor for a natural or cultivated soil surface, bare or covered with vegetation, is usually at or near this limit.

Increased resistance to flow over sod is therefore due mainly to increased friction surface. Alternate expansion and contraction of the water filaments in the tortuous passageways through the grass also plays a part. This partially accounts for the observed limitation or absence of surface erosion on sodded ground. At the same time, reduction of velocity carries with it a corresponding increase of the average depth



EFFECT OF SUBDIVISION OF FLOW ON VELOCITY OF OVERLAND FLOW

FIGURE 12.

of surface detention and a consequent decrease of surface run-off. This, combined with the other factors mentioned, fully accounts for the observed phenomena.

There are undoubtedly large areas, particularly in the semiarid region, where ordinary agricultural practices are bringing about destructive effects on a large scale. There seems to have been a natural ecological balance between the Indian and buffalo and native grasses of the plains region, and drastic changes in agricultural practice must evidently be brought about if this balance is to be restored. Man is, however, a graminivorous animal and we cannot all live, like Nebuchadnezzar, on grass. Fortunately, fall-sown grains and grain stubble after cutting and even weeds bring about in a considerable degree hydraulic benefits similar to those obtained by grass sod.[15]

RELATION OF SURFACE RUN-OFF CONTROL TO PLANT GROWTH AND GROUND WATER

Infiltration to a dry soil penetrates initially only to the depth to which the volume of infiltration can restore soil moisture to field moisture capacity. Moisture is therefore first restored in the topsoil containing the surficial root zone. Subsequent translocation or downward movement of this moisture is relatively slow unless infiltration again occurs.

Consider a soil column with initially a large field moisture deficiency throughout its depth. Unless the first increment of soil moisture is depleted in the meantime, the next accretion through infiltration penetrates to a greater depth, and so the soil moisture is gradually restored to field moisture capacity, step by step, from the surface down to the water table. The larger the increments of accretion, the quicker full restoration occurs.

Infiltration occurs during all rains; therefore surface run-off control does not increase the frequency of occurrence of infiltration although it may greatly decrease the frequency of occurrence of surface run-off. It does not increase the amount of infiltration in light rains, since all rain is absorbed if the rain intensity is less than the infiltration capacity. The increase takes place through larger increments in all rains with intensities exceeding infiltration capacity.

While further researches are needed, taking into account hydrologic as well as agricultural aspects of the subject, it appears that surface run-off control will benefit plant growth through (*a*) better sustained soil moisture in the surface root zone under normal conditions, (*b*) greater soil-moisture reserves at the inception of droughts and (*c*) quicker restoration of moisture available to deep-rooted plants when drought ends.

Increased infiltration redounds of necessity either to the soil-moisture zone or to ground-water storage. Vegetation has the first chance but if a given increment of infiltration is not used by plants, an equal amount of accretion to ground-water storage will take place subsequently.

LEACHING OF THE SOIL

All methods available for reducing run-off depend, and must necessarily depend, on some means of increasing the infiltration capacity, providing a longer-sustained infiltration capacity above the minimum, or by increasing surface detention and with it the duration of infiltration at capacity rate. It has been suggested that any method which increases the infiltration will also increase the loss of nutrient material from the soil by leaching. This is an incidental and unavoidable evil. The soil is practically never destroyed by leaching, probably for the reason that the combined action of sun, air, and rain on newly exposed material converts it into a form available for plant use, that is, matures the soil as fast as or faster than previously available nutrient material is removed by leaching.

With reference to leaching, it may be noted that long lysimeter records are available, par-

[15] Kramer and Weaver, *Relative Efficiency of Roots and Tops of Plants on Protecting the Soil from Erosion*, Bull. 12, Conservation Dept., University of Nebraska, 1936.

ticularly those at Rothamsted, in England, and elsewhere, which afford valuable information on this point. It happens that the lysimeters used have in general been so constructed that all of the rain is absorbed by the soil, that is, they are without overflows and no surface run-off can take place. Under these conditions the leaching is obviously the maximum amount possible and hence the data from these lysimeter records will show the greatest amount of loss by leaching which can take place in the most effective control by terracing or other methods.

SURFACE RUN-OFF CONTROL AS DROUGHT INSURANCE

The physiological effects of droughts, particularly their effect on plant growth, differ materially from their phreatic and potomalogical effects, that is, their effect on ground water and stream flow.

Water in the soil available for plant use is that lying between the wilting point as a minimum and the field-moisture capacity of the soil as a maximum. When water enters the soil by infiltration it is all held in the soil above the water table until the soil moisture is built up to equality with the field-moisture capacity in the entire soil column from the soil surface down to the water table. Thereafter all additional infiltration goes directly into the ground-water reservoir. Excepting as it may be removed by evaporation or by transpiration through plants, soil moisture remains permanently within the soil. Ground water, on the other hand, is gradually exhausted by outflow to streams, lakes or oceans, at a rate nearly or precisely proportional to the volume of ground water remaining in the aquifer. During a prolonged drought, both soil moisture and ground water become severely depleted. When rain comes the infiltration all goes to replenish soil moisture until this is restored to field-moisture capacity. This may require months although it is usually attained within a single annual hydrologic cycle.

As soon as the soil-moisture content rises well above the wilting point, the physiologic drought is ended, except in case of such trees and other plants as depend in part directly on the water table for their moisture supply. The phreatic drought continues with slowly increasing intensity until the soil moisture is restored to field-moisture capacity and usually longer. Since moisture to replace transpiration is continually taking its toll out of infiltration, and ground-water outflow still goes on, restoration of ground-water storage to normal often takes 1, 2, or even several years after the end of physiologic and meteoric droughts. In the meantime wells are low and streams fall quickly and to abnormally low levels during rainless periods.[16] It has been shown that soil moisture is replenished mostly from shorter, more frequent rains, while the ground-water reservoir is rarely replenished except from long-continued, heavy, infrequent rains, and would not be replenished even from these excepting for the reduction of field-moisture deficiency by shorter, more frequent rains. It has been shown that there are various ways in which infiltration can be increased in conjunction with surface run-off control. Any increase of total infiltration will necessarily result in reduction in the duration and intensity of physiologic droughts by increasing the soil-moisture content when drought begins and reducing the time required to restore soil moisture to its field capacity when rains come. Likewise, there will usually be more ground water in storage when drought begins and a shorter lag interval in restoring phreatic water to normal after physiologic drought ends.

In order to determine how and to what extent drought insurance may be attained in this manner, comprehensive studies are needed of drainage basins where run-off phenomena are completely determined and ground-water level records are also kept and published.

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[16] There seems to be evidence that trees supplied in part from the water table sometimes die a year or two after physiologic drought has ended, owing to the cumulative lowering of the water table.

SUMMARY AND RECOMMENDATIONS

Surface run-off can be controlled or reduced by (*a*) increasing the length of overland flow, (*b*) decreasing the surface slope, (*c*) increasing depression storage, (*d*) increasing the infiltration capacity of the soil.

To the extent that these may be accomplished, the following results will be attained: (*a*) Surface run-off will be decreased; (*b*) total infiltration will be increased to an equal extent; and (*c*) surface run-off intensity will be decreased in shorter storms by all four processes described, but increase of infiltration capacity is the only certain means of reducing surface run-off intensity in prolonged storms such as produce maximum floods.

Processes other than direct increase of infiltration capacity increase the total infiltration by increasing the depth or volume of surface detention and consequently increasing the duration of infiltration.

Changes in the surface phase of the hydrologic cycle will not change total run-off unless there is also a change in water losses, particularly transpiration. An increase of transpiration accompanied by an equal or larger increase of infiltration will cut down surface run-off without decreasing ground-water flow. In arid regions where there is no perennial ground water, vegetation usually uses all available infiltration.

In humid regions, increased infiltration will usually be divided between increased plant use and increased ground water, providing both increased plant growth or crop yield and better sustained and more uniform ground water and stream flow. To whatever extent it can be brought about, increased infiltration capacity of the soil will reduce maximum intensities of surface run-off and with it maximum flood intensities, directly in proportion to the increase of infiltration capacity.

The fundamental basis for surface run-off control and soil surface engineering is complete knowledge of the hydrology of the surface phase of the hydrologic cycle. Practical application to a given area requires adequate data of topography and soil conditions. To supply these the following recommendations are made:

1. Immediate completion of the topographic map of the United States [17] in accordance with the plan proposed by the National Resources Board 2 years ago, including revision of inadequate maps and reduction of contour interval to 10 or even 5 feet where desirable, for use in planning soil-surface engineering or for other uses.

2. Drastic revision and early completion of the soil maps of the United States, including on these maps data which will make them definitely quantitative. All maps should have contour lines showing the moisture equivalent of the soil down to say 8 inches or to full depth of tillage. Where the subsoil is different, the moisture equivalent of the subsoil could be given by figures. The present system of designation of soil types is hopeless except to professional soil technologists. As a random suggestion, a definite meaning would be imparted if the soils were designated by number as well as type name, the numbers indicating percentages of sand, silt, and clay. The simplest scheme would be numbers adding up to 10, and denoting to the nearest 5 percent the percentages of these constituents. Thus a soil containing 43 percent sand, 29 percent silt, and 28 percent clay would be put on the soil map as a 4.3.3 soil. This scheme could of course be elaborated to any degree which is practicable.

3. A large number of run-off plat experiments are now being carried out. In some cases these are not equipped with recording gages for run-off. All plats should be so equipped and all data accumulated which are reasonably reliable should be immediately published in full, giving details or graphs, for each stream, of rain intensity and run-off intensity. These data form a basis for determining not only infiltration capacity but the law of surface run-off for different

[17] See Letter from William Bowie, *Eng. News-Rec.*, Aug. 13, 1936, p. 247.

types of soil surface. In addition it may be noted that every stream flow record, particularly for smaller drainage areas, if accompanied by adequate rainfall data, forms a potential basis for determining the average infiltration capacity over the entire drainage basin involved.

4. One objective of surface run-off control is to provide higher stages and a more uniform regimen of ground water in the surface aquifer. Many ground-water level records are kept but few are published. Immediate publication of all available ground-water level records, the establishment of new ground-water record stations and periodic publication of all records, preferably in the form of tables giving daily ground-water levels, is strongly recommended. Too much stress has been laid on the study of deep or artesian aquifers—not enough on the more widespread and economically important nonartesian or surface ground water. While recording gages are desirable, daily records suffice for most purposes. These can often be obtained at little expense in connection with the collection of rainfall and stream flow data.

5. Rain intensity and duration are more important than total rainfall in relation to all problems involving surface run-off and infiltration. The number of rainfall stations equipped with recording rain gages should be greatly increased, especially in agricultural regions.

6. Records of hourly rainfall are regularly compiled for all stations with recording rain gages. Few of these are published. Immediate provision should be made for publication of these records and for future publication of all such records in "Climatological Data" or elsewhere. This will not be as costly or cumbersome as might be inferred, since entries need be printed only for days with more than a trace of rain.

The practice now common in Government bureaus of carrying out extensive experimental researches and publishing only the investigator's conclusions, without the basic data, cannot be too strongly condemned and should be forthwith discontinued. Such data may be and often are vastly more valuable for other purposes than for the purpose for which they were collected.

The lavish expenditure of money in the collection of data, accompanied by a parsimonious policy in the matter of publication of the data, retards instead of advances science.

DISCUSSION

1. Walter N. White
Senior Hydraulic Engineer, Water Resources Branch, U. S. Geological Survey, Department of the Interior, Washington, D. C.

Mr. Horton has made in his paper a most excellent statement of the fundamental principles governing infiltration and run-off, which have been recognized by students of the subject for some time but heretofore have not been brought together so completely in one paper. He has said very little about the increment of infiltration that passes through the soil and subsoil and is stored in the zone or zones of saturation.

For a considerable number of years I have been occupied on water-supply investigations in which the study of the annual rate of replenishment of the underground reservoirs has been an essential part. It appears, therefore, that I can best serve this meeting by a discussion of this form of storage and of the possibilities of controlling ground-water intake and thereby increasing the supply in storage. Of course, in the brief time available, it will be possible only to touch a few phases of this important subject. The terms "ground water" and "underground reservoirs", as used in this discussion, relate to water supply and storage facilities in the zones of saturation. In a given locality there may be one or more perched zones of saturation as well as the lower zone whose surface is the true water table.

Anyone who pays any attention to the subject soon realizes that nature, in bestowing resources of underground water, has treated different sections of the country very differently. In some

sections she seems to have been lavish in her gifts, in others less liberal, and in still others positively stingy. When we inquire into the conditions of ground-water occurrence, the reasons for this apparent partiality are quickly revealed. The rainfall has a good deal to do with it, for, other things being equal, the supply of ground water is greater in humid regions than it is in arid regions. The next most important factor, however, is the capacity of the rocks that underlie the soil and subsoil to absorb and store water and to transmit the water and yield it to springs, streams, and wells. In a geologic sense, sand and gravel, it should be pointed out, are classified as rocks. Unless one is familiar with the character and geologic structure of the rocks that underlie a region it is difficult to understand fully the occurrence of ground water and certainly impossible, in most areas, to reach a sound conclusion as to the feasibility of controlling even to a small degree the ground-water recharge and discharge.

The underground reservoirs are among our most valuable natural assets. In the aggregate the quantity of water stored in these reservoirs greatly exceeds the capacity of all surface reservoirs in the country, both natural and artificial, possibly excluding the Great Lakes. In the country as a whole approximately half of our population is dependent upon the underground reservoirs for water supply, and for the rural population the proportion is even greater. The underground reservoirs ordinarily respond much more slowly than the surface reservoirs to the effects of drought, and water supplies derived from them, especially from the larger and deeper reservoirs, usually are secure during a succession of dry years, unless the withdrawals of water are excessive. Nevertheless, it is well worth while to give serious consideration to any method that may accelerate the replenishment of the underground reservoirs, including those employed in the control of soil erosion in areas which are subject to excessive drought or in which the demands for ground water are very heavy.

RELATION OF GROUND-WATER STAGE TO VARIATION IN RAINFALL

In any program of upstream research serious thought must be given to the question whether the area under investigation is passing through a wet, dry, or normal period in the climate cycle; otherwise, an entirely wrong idea may be obtained as to the water resources of the area, especially as to the ground-water resources. Considerable popular apprehension has developed in recent years from the belief that groundwater supplies generally throughout the country are being seriously impoverished as a result of the cultivation of lands that formerly supported a growth of grass or timber, the drainage of lands and ponds, and the effects of other factors. Some geologists and engineers have shared in this feeling of alarm; others have not. Undoubtedly there has been a pronounced lowering of water levels in the wells in some parts of the country at times in recent years, especially during the droughts of 1930 and 1934. It has been plainly evident to some of us, however, that except in areas in which there has been overpumping or widespread artificial drainage, the lowering has been a normal fluctuation, chiefly because of a periodic cycle of fluctuations in rainfall, and that the water table may be expected to rise again in the subsequent wetter part of the cycle. This opinion is unanimous among the members of the division of ground water of the United States Geological Survey, and it is substantiated by long-time records of water-table fluctuations in different parts of the world, such as the 100-year record of a well in the chalk of England, mentioned by Horton,[18] the long-time records of wells in southern California, some of which were started about 40 years ago, and records of wells on Long Island.

In the course of a ground-water investigation in southern California in 1904–5 by the United States Geological Survey under the supervision

[18] Horton, R. E., Maximum Ground-water Levels: *Am. Geophys. Union Trans.* 17th Ann. Meeting, pt. 2, p. 351, 1936.

of Dr. W. C. Mendenhall, now director of the Survey, it was found that nearly everywhere during the preceding 10 years there had been a material lowering of the water levels and artesian pressures in wells, the lowering in a few places amounting to 100 feet or more. Many of the pumping-plant owners were predicting widespread disaster, because then, as now, much the greater part of the water supply developed in southern California came from wells. A few foresighted engineers pointed out, however, that the State had been passing through a long cycle of dry years and predicted that with increased rainfall the water levels would rise again. This prediction was abundantly justified. Beginning in 1905 and continuing until 1916, the rainfall was above average, and the water levels in the observation wells in most of the area displayed a long and persistent rise, despite the continued heavy draft on the underground supplies.[19] [20]

Nassau County, Long Island, has been settled for more than 300 years and is now densely populated. There is good evidence that in this county the water table was lower about 1860, at the end of a 30-year period of markedly deficient rainfall, than it has been at any time since careful measurements of wells were begun, in 1903, in spite of heavy pumpage of ground water for the City of New York public supply.[21]

The belief that the present conditions of low water table are temporary seems to be further substantiated by recent records of water-level fluctuations in parts of the drought-afflicted region in the Mississippi Valley, which show that the water table made a marked recovery in 1935, after the drought of 1934, and that although a part of the recovery has since been lost, the water levels in observation wells in at least parts of the region were higher on September 1, 1936, than they were on September 1, 1934.[22] Much enlightening and hitherto unpublished information in regard to the interpretation of the apparently low ground-water levels in recent dry years is contained in a symposium of 12 papers published only a few days ago in the Transactions of the American Geophysical Union for 1936. Water-Supply Paper 777 of the United States Geological Survey, giving the results of water-level measurements in about 3,000 wells in 14 States, is now in press.

It is true that in certain areas, mostly not very greatly affected by the drought, there has been a serious decline in the water table or in the artesian pressures in the underground reservoirs, owing to heavy withdrawals of ground water for irrigation and for municipal and industrial uses. In some of these areas it is evident that the draft on the water-bearing beds is in excess of their natural capacity to yield water in accordance with well-recognized principles of hydrology. In many of these areas it will be impossible to improve conditions materially, and the only apparent way to prevent permanent overdraft is to reduce the pumpage from the aquifers. For example, in areas underlain by dense impervious shale, such as the Pierre shale in Montana, check dams, water spreading, contour plowing, or other remedial measures cannot generally improve ground-water conditions. Likewise, in the Dakotas similar methods cannot possibly increase the supply of water or the artesian head of the Dakota sandstone where it is overlain by several hundred feet of impervious rocks. Where such unfavorable conditions exist and no other aquifers are available, surface reservoirs may be the only effective means of providing some increase in water supply.

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[19] Ebert, F. C., *Water Levels in Wells in Southern California*, U. S. Geol. Survey Water-Supply Paper 468, 1921.

[20] Ebert, F. C., An Interpretation of Water-Table Fluctuations at Four Wells in Southern California: *Am. Geophys. Union Trans.*, 17th Ann. Meeting, pt. 2, pp. 371–377, 1936.

[21] Legette, R. M., Long-Time Records of Ground-Water Levels on Long Island, New York: *Am. Geophys. Union Trans.*, 17th Ann. Meeting, pt. 2, pp. 341–344, 1936.

[22] Recent unpublished records in files of U. S. Geological Survey, Washington, D. C.

IMPORTANCE OF GROUND WATER IN STREAM DISCHARGE

One of the requisites of upstream engineering research is to make separate computations of storm-water run-off and ground-water run-off for each drainage basin. In some recent investigations of the relation between rainfall and run-off special attention has been given to such computations. The subject has been treated at considerable length by W. G. Hoyt [23] and others, under the sponsorship of the National Resources Committee. Their computations show that the discharges of several streams in different parts of the United States are sustained in considerable part by ground water for periods of weeks or even months. A study by Harrold [24] of the discharge of the northwest branch of the Anacostia River, near Washington, D. C., shows that the stream was probably fed wholly or almost wholly by ground water during about four-fifths of the 17-month period of observation.

Horton and the investigators just named have used the hydrograph-depletion curve method of differentiating between surface and ground-water run-off, which is the most convenient method because it can be applied to past long-time records of stream flow. The channel storage method, some engineers think, is more accurate. An investigation in which the channel storage method is employed was made by the United States Geological Survey on a small headwater of Difficult Run, which enters the Potomac River in Virginia near Washington. Certain results of this investigation are noteworthy.[25] The storm run-off is carried away very quickly; the water table in most areas along the stream rises sharply in response to moderate or even small rains; this rise is quickly followed by an increase in the ground-water discharge of the stream.

Although these studies so far have covered only a few streams, they undoubtedly have application to many other streams in different parts of the country. They serve to place on a reasonably accurate quantitative basis the important part that ground water plays in stream discharge, especially during the critical periods of low flow. Is it possible to increase the supply of ground water in storage and thereby to increase the critical low flow of the streams by the control and increase of direct infiltration from rainfall, by methods involved in the process of soil conservation, by constructing check dams to hold flood water for a time and give it an opportunity to sink underground, by spreading flood water on selected areas where conditions are favorable for rapid infiltration, or by the introduction of flood water into wells?

POSSIBILITIES OF INCREASING GROUND-WATER SUPPLIES

In considering the possibilities of artifically increasing ground-water supplies a few fundamental concepts should be kept in mind. (1) The total amount of water that can be added to the underground reservoirs of the country generally by practicable artificial methods will necessarily be very small in comparison with the total natural ground-water recharge from rainfall. (2) The amount of water consumed by evaporation and by transpiration of vegetation is enormous. The losses continue after the water reaches the water table, if the water table and its attendant capillary zone are near enough to the surface to be depleted by evaporation or by transpiration of plants, some of which are very deep-rooted.

In the course of a ground-water investigation in the Mimbres Valley, N. Mex.,[26] a few years

[23] Hoyt, W. G., and others, *Studies of Relations of Rainfall and Run-off in the United States:* U. S. Geol. Survey Water-Supply Paper 772, 1936.

[24] Harrold, L. L., Relation of Stream Flow to Ground-Water Levels: *Am. Geophys. Union Trans.* 15th Ann. Meeting, pt. 2, pp. 414–416, 1934.

[25] Meinzer, O. E., and others, The Channel-Storage Method of Determining Effluent Seepage: *Am. Geophy. Union Trans.* 17th Ann. Meeting, pt. 2, pp. 415–418, 1936.

[26] White, W. N., *Preliminary Report on the Ground-Water Supply of Mimbres Valley, N. Mex.*, U. S. Geol. Survey Water-Supply Paper 637, p. 86, 1931.

ago it was found by excavating a pit that the roots of a mesquite tree reached ground water in an area in which the water table was 48 feet below the surface. In a recent investigation in Kansas diurnal fluctuations of the water table were observed in a well near Mankato that were almost certainly due to withdrawals of ground water by a nearby grove of trees, although the water table was about 43 feet below the surface.

Numerous examples have been noted of the effect of the consumptive use of water by vegetation on the ground-water flow of small streams, especially during droughts. The behavior of a small stream at Cabin John, Md., near Washington (see Monthly Weather Review for October 1930), which has a drainage area of only a few acres and is in effect a spring, was typical of that of numerous other springs and small streams in Maryland and Virginia during the drought of 1930. During the summer there was a diurnal fluctuation in which the low flow was at times only one-sixth of the high flow.

Gage-height records on many streams in different parts of the country have disclosed marked diurnal fluctuations during dry periods because of evaporation and transpiration in areas of shallow ground water closely adjacent to the stream bed. Among such streams are the Santa Ana River and several other streams in California, several creeks in Utah, the Mimbres River in southern New Mexico, the South Fork of the Mills River at the Pink Beds, N. C., Piney Run near Sykesville, Md., and Owens Creek at Lentz, Md. J. C. Hoyt[27] estimated that during June 1 to 5, 1932, variations in the flow of Owens Creek because of evaporation and transpiration averaged over 20 percent of the daily flow and amounted to 820,000 gallons a day—enough to furnish an average municipal supply for 8,000 people.

Perhaps the most accurate conception of run-off is the one which regards it merely as the residue from rainfall after evaporation and transpiration have taken their heavy tolls. The effects of evaporation and transpiration must be taken into account in any plans for inducing artificial ground-water recharge and a consequent rise in the water table.

[27] Hoyt, J. C., *Droughts of 1930–34:* U. S. Geol. Survey Water-Supply Paper 680, p. 20, 1936.

Artificial Methods of Ground-Water Recharge

It seems probable that in areas where conditions are favorable for deep penetration, some increase in ground-water recharge will follow the widespread application of such methods of soil-erosion control as terracing or contour plowing, but practically nothing is thus far known regarding this important subject. A program of well-level observations being carried out by the Soil Conservation Service in connection with some of its experimental work may throw some light on the matter, although the program apparently is not as complete as could be desired.

Artificial methods of recharge for the special purpose of increasing the ground-water supplies have been successfully practiced at several localities in Europe and the United States. Thus far the greatest success has been accomplished by diverting comparatively clear water from the streams to selected spreading grounds where conditions are favorable for rapid infiltration and deep penetration, the muddy water of the early stages of storm run-off being allowed to pass on downstream.

Water spreading to increase ground-water recharge has been practiced in California for a long time, the first experiments being made about 40 years ago. It is employed in San Fernando Valley to store the surplus water from the Owens aqueduct. On the Santa Ana and San Gabriel Rivers and a dozen smaller streams in Los Angeles and San Bernardino Counties, on the Santa Clara River in Ventura County, on Santa Clara Creek in Santa Clara County, and in parts of the San Joaquin Valley flood water is diverted and spread immediately on selected infiltration grounds or held back by dams and

gradually released to the stream channels for natural infiltration. On some of these projects efforts that seem promising are being made to use muddy water, the water being kept in motion by different methods. Nearly all these projects are located in areas where the geologic and hydrologic conditions are exceptionally favorable for ground-water recharge, most of them on alluvial cones or outwash slopes composed of relatively coarse, permeable materials where the water table is at relatively great depths beneath the surface. Several projects have been tried in California for putting water underground by means of wells and shafts, but the results have generally not been very satisfactory. Apparently recharge by running water into wells has been successful only where the wells penetrate rocks containing large openings, such as solution channels in limestone. The entire storm run-off and sewage of a considerable area in the vicinity of Orlando, Fla.[28] is disposed of in this way, and the method has been used in other localities underlain by limestone. In the Salt River Valley, Ariz., several hundred thousand acre-feet of water is pumped each year from wells, practically all of which is derived from infiltration to the water table from irrigation, the oldest form of water spreading. Many pages of discussion and reports have been devoted to these projects and are available to anyone who cares to look them up.

The results of water-spreading operations in California are discussed in reports of the State engineer, the Bureau of Water Works and Supply of Los Angeles, and the Bureau of Agricultural Engineering of the United States Department of Agriculture, and in papers published in the Transactions of the American Geophysical Union of the National Research Council and in various engineering periodicals. The most recent article of which I have knowledge is one by D. A. Lane, in the Journal of the American Water Works Association for September 1936, pages 1241–1251, entitled "Artificial Storing of Ground Water by Spreading." All these reports contain valuable information for the engineer who is interested in upstream engineering, especially in areas where there is an overdraft on the underground supplies.

[28] Stringfield, V. T., *Ground-Water Investigations in Florida:* Florida Geol. Survey Bull. 11, p. 21, 1933.

SOME GENERAL CONSIDERATIONS OF ARTIFICIAL METHODS TO CONSERVE WATER BY STORAGE IN UPSTREAM AREAS

In connection with artificial methods of increasing the ground-water supply it is necessary to consider the conditions that may result from changing the regimen of the streams by upstream engineering projects. Some phases of this problem, relating only to the effects of storage of surface waters, were discussed by Gerard Matthes [29] at the meeting of the American Geophysical Union in 1934. I can only mention some possibilities to be considered in regard to ground water and natural ground-water recharge. While investigating ground-water recharge in Utah, Arizona, and New Mexico I have frequently been impressed with the natural facility of streams having sandy beds for absorbing muddy water in great quantities and thereby supplying underground reservoirs, from which thousands of acres are irrigated. The sand serves as a natural filter, which is renewed by scouring of the stream bed and resorting of the stream-bed materials by the front of each successive flood, the silt deposited by the preceding flood being carried down to lower reaches of the stream and usually deposited in layers on the valley floor. A similar natural process is believed to be common in most losing streams everywhere, and methods for artificial recharge clearly should disturb it as little as possible. If check dams are used they must be low and not interfere too much with the natural floods.

It would seem rather obvious that efforts to

[29] Matthes, G. H., Floods and Their Economic Importance: *Am. Geophys. Union Trans.* 15th Ann. Meeting, pp. 427–432, 1934.

increase infiltration from any surface stream, large or small, by means of check dams, water spreading, or other methods can be successful only where the water table lies below the level of the stream; likewise, that care must be taken that the damage to the natural infiltration facilities because of silting of the stream channel or clogging of the pores of the spreading grounds by silt does not more than counterbalance the benefits of the operations. The geologic and hydrologic conditions must be such that an increase in ground-water storage will not produce undue damage to already existing interests and activities. Artificial recharge may reduce floods and increase the low-water flow downstream by increasing the ground-water flow, but on the other hand, in some localities it may raise the water table so far as to produce damaging seepage. In other localities a change in the regimen of the stream may result in a deficiency in stream flow in downstream stretches where the present activities—for example, irrigation or navigation—have been built around natural conditions as they existed years ago, before being modified by the hand of man.

In conclusion I wish to say that in common with most other hydraulic engineers I am heartily in favor of any efforts of upstream engineering that look to a better use of the land and water of the country, but I urge as one of the first and most important steps in such efforts an adequate study of the hydrologic and geologic conditions that may affect the final natural balance of the hydrologic cycle, not merely in the upstream area but in any downstream part of the drainage basin or even in adjacent drainage basins.

2. George S. Knapp

Chief Engineer, Division of Water Resources, Kansas State Board of Agriculture, Topeka, Kans.

In the letter transmitting copies of his paper to those who have been requested to discuss it, Mr. Horton expressed the hope that farm ponds would be fully discussed. This discussion relates principally to that subject, and will be limited, for the most part, to the conditions in Kansas.

Kansas was early among those States that appreciated the need for the storage of surface run-off in numerous ponds and lakes on headwater draws and ravines. Evidence of this need was manifest, both by public interest and legislation directed toward encouraging such storage. In 1911 the first act was passed. It provided that any landowner who, by the construction of a dam across any dry watercourse, formed upon his land a reservoir for the collection and storage of surface water should be entitled to a reduction in the assessed valuation of his land of $100 for each such dam, if constructed of earth, and $200 per dam if constructed of stone. The landowner was limited in the reduction to not more than three such dams on each 160 acre-tract.

No information is available as to the number of such dams built, but the legislation did not result in any extensive permanent construction program. There were two reasons for this inactivity: First, the reduction was not sufficiently large to induce landowners to construct dams unless they were definitely in need of water, and few of them were in normal times. Second, there was no public supervision over plans and construction. The result was that dams were poorly built. Most of them had insufficient spillway capacity to pass safely surplus flood waters around the dams and were therefore overtopped and destroyed when the first heavy rain came.

In 1928, following the extensive floods of the year before, the Governor of Kansas appointed a committee on flood control and water conservation. This committee, among other things, considered the matter of the conservation of water on small draws and ravines. It recommended that the act of 1911 be revised to provide a greater reduction in assessed valuations for such storage by making the amount of the reduction proportional to the amount of water which the dam would store, to require that plans for such dams be prepared by a competent engineer and be approved by the division of water

resources, and to provide that the dams be satisfactorily completed in accordance with approved plans before the reduction in the assessed valuation of the land be made effective. The writer was a member of that committee and personally drafted the revised measure. It was enacted into law by the legislature of 1929, and resulted in renewed activity in the construction of such storage. The reduction in assessed valuation, $75 per acre-foot of storage capacity, however, proved to be too great. Some large landowners, who were financially able to do so, set out to construct sufficient storage to wipe out entirely their land taxation. As a result of this the legislature of 1933 reduced the reduction to $40 per acre-foot and added a provision that the total amount of such reduction should not exceed 40 percent of the assessed valuation of the land. In 1935 the legislature further amended the law to provide that plans for dams less than 10 feet in height, when storing less than 15 acre-feet of water, should be under the jurisdiction of the county engineers of the respective counties, leaving only the plans for the larger structures to come before the division of water resources.

Information is not available as to the number of the smaller dams built. Up to September 1936, plans for 2,287 dams more than 10 feet in height or impounding more than 15 acre-feet of water have been approved by the division of water resources. Most of these have been built or are under construction. These have a combined storage capacity of more than 36,000 acre-feet and receive the run-off from 3,970 square miles of land.

Kansas looks to the ultimate construction of 50,000 of these reservoirs. This would provide one for approximately each square mile of area of the State, except for that portion of the tertiary high plains in the western part which is so level that no surface run-off takes place.

The primary purpose or value of these ponds is to provide water supplies in the localities in which they are built. Other benefits and limitations will be discussed later. Throughout the State natural water storage, except in the ground, is nonexistent. In extensive areas there is no permanent ground-water supply. The water table fluctuates widely between wet and dry periods. In prolonged or severe periods of dry weather wells fail and it becomes necessary to dispose of livestock because farmers are without water for them. Municipal wells fail and water must be hauled from distant sources. The storage of water in numerous ponds and reservoirs will keep water where it is needed. The storage already built has demonstrated its worth, and the completion of the storage program planned in this State will remove all question of water supply during periods of drought.

Surface storage will also increase subsurface storage. In that portion of the State covered by deposits of tertiary age, the surface storage is above the water table. Percolation from reservoirs will, therefore, contribute to the ground-water supply found at the base of the tertiary deposits throughout the Great Plains region. The opportunities for storage in that region, however, are limited because of the flatness of the surface. Further, it might be added, water supply in the tertiary deposits has always been adequate for such use as has been made of it, that is, for domestic use and stock watering, for municipal use and, to some extent, for irrigation.

In other parts of the State there is no permanent water table except in the flood plains of the streams. Surface storage in draws and ravines will in general be located below such ground-water supplies as are found in the upland, and hence, will not contribute to such supplies. Ravines and small creeks are usually filled with detritus washed down from above. These contain ground water during normal conditions of rainfall, but it drains out almost completely during protracted droughts. Wells are frequently located in these ravines and they, of course, fail in dry periods.

It is in the draws, ravines, and small creeks that the surface storage program will make the

greatest contribution to subsurface water supplies. In the construction of small dams in this State, it is not the purpose to cut off all porous material underneath the dam provided it, for some of it can be left without endangering the stability of the structure. Percolation from the reservoir is thus definitely permitted and even provided for. This percolating water, proceeding down through the valley fill, provides a continuing water supply for wells below and in some instances it establishes perennial flow in channels which before had only intermittent flow.

It does not seem probable that such storage will increase rainfall, eliminate droughts, or measurably reduce destructive floods. In the first place storage in the Great Plains region cannot materially increase the proportion of the rainfall returned to the air as transpiration from vegetation or evaporation from land and water surfaces. That will be apparent if we consider such a typical western area as the Kansas River Basin above Topeka. The area drained by the Kansas River, 60,000 square miles, includes besides nearly the north half of Kansas, the southern part of Nebraska and a portion of eastern Colorado. It receives an average annual rainfall of 24 inches. The run-off from this area amounts to an annual average of a little less than 1 inch. Evaporation and the use of water by growing crops consume the balance, or 96 percent of the rainfall. Obviously, if the entire run-off could be stored and returned to the air as vapor, it could increase the amount so returned now by but 4 percent. From a physical standpoint, it would be impossible to store the entire run-off, and from a practical standpoint it should not be done, because of the needs of the cities along the main portion of the stream. It is perhaps pertinent to the discussion to add that the problem of making more of the rainfall available for growing crops in this region is more largely one of getting a greater percentage of the rainfall, now evaporated, into the soil beyond the reach of evaporation before it can be recaptured, rather than one of materially reducing the percentage of rainfall that now runs off.

Run-off is somewhat higher in eastern and southeast Kansas, being about 4.4 inches on the Marais des Cygnes, 5.2 inches on the Neosho, and 7.6 inches on the Verdigris.

Again, the storage considered here is not sufficient in amount, nor is it of such a character as to affect appreciably destructive floods. Reservoirs such as these will be filled from normal run-off—that is, from small freshets. The capacity of small reservoirs on headwater ravines is governed largely by local conditions of topography. In Kansas, the capacities of those constructed vary from about 25 acre-feet per square mile of drainage area in the eastern part of the State to less than 5 in the western part, with an average of about 10. Studies made by the division of water resources indicate that some eastern Kansas streams would require an available storage capacity of about 250 acre-feet per square mile to control destructive floods on those streams. Ordinarily but a small part of the rainfall runs off. Floods occur only where heavy or continuous rain takes place after earlier rains have saturated the soil and reduced the infiltration capacity to a low point. By that time the small reservoirs have also been filled to capacity and must pass all additional run-off through their spillways.

For a complete storage program, it is evident that we should have flood-detention reservoirs as well as small conservation reservoirs. In Kansas, reservoirs or lakes are needed for recreational purposes and in some instances also for municipal water supplies. In outlining a comprehensive water-storage program to meet various needs of the State, Kansas is making provision for numerous farm ponds, for recreational lakes in all parts of the State, for municipal reservoirs for those cities in need of better water supplies, and for large flood-detention reservoirs at suitable locations to control destructive floods. Such a program could well be considered by many States, particularly those in the Great Plains belt.

CHAPTER III

GIVING AREAL SIGNIFICANCE TO HYDROLOGIC RESEARCH ON SMALL AREAS

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U. S. DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.[1]

THE PIONEER STAGE in the conservation of soil and water is believed to have passed. Public consciousness of soil erosion as a form of national wastefulness is well developed. Programs of research have been initiated, designed not only to aid in immediate planning but ultimately to deal analytically with hydrologic problems which have now only empirical solutions. Practical steps have been taken to put to immediate use such preventive and remedial measures as our limited experience has shown to be effective.

In soil and water conservation, as in any newly developed science, that which appears to be new loses much of its originality when the unrelated and fragmentary experiences of the past are assembled and coordinated. The scourge of soil depletion has been held at bay by the occasional practical-minded American farmer who saw in the land more than the opportunity for exploitation throughout his tenure of ownership. The ancients, both of the old and new world, have contributed to present-day knowledge of conservation methods. Several of the Federal agencies have done effective exploratory work.

From these experiences, and the results of our own too brief period of research, have been drawn the tentative rules for conservation. Within the Soil Conservation Service the approach has been on a regional basis in order that such dominant factors as climate, physiography, soil types, natural vegetal cover, established crops, and social adjustments may be properly classified and evaluated.

Engineering experiments, including hydrologic studies, were started during 1929–31, under the direction of C. E. Ramser, then Senior Drainage Engineer, Bureau of Agricultural Engineering, on 10 erosion experiment stations established at Guthrie, Okla.; Hays, Kans.; Temple, Tex.; Tyler, Tex.; Bethany, Mo.; Statesville, N. C.; Zanesville, Ohio; La Crosse, Wis.; and Clarinda, Iowa. These stations were operated jointly by the Bureau of Agricultural Engineering and the Bureau of Chemistry and Soils, United States Department of Agriculture. The stations were transferred in 1935 to the Soil Conservation Service and are now being operated under the Section of Soil and Water Conservation Investigations, Division of Research.

These investigations embraced the study of erosion processes and the evolution of effective erosion prevention and control methods, such as plowing and cultivation, terracing, strip cropping, and crop rotation. They also included the isolation and evaluation of those influences affecting the rate and volume of run-off and soil

[1] The author wishes to acknowledge his indebtedness to Ivan Bloch, Associate Engineer, of the Rural Electrification Administration, for technical assistance of the highest order. Mr. Bloch assisted in the development of the method described and prepared many of the graphs and figures entailing several hundred hydrograph translations. The author is indebted to Herbert Thom, Henry Rockwood, H. C. Murto, and L. L. Harrold, of the Section of Watershed Studies, Soil Conservation Service, for review and collaboration in the preparation of the text. He also wishes to thank C. E. Ramser, Senior Soil Conservationist, Soil Conservation Service, for the selection and description of the graphs of rainfall and run-off observed on the erosion experiment stations, and shown in figs. 26 to 32, inclusive.

loss, such as slope, type of soil, grade and spacing of terraces, vegetal cover, and intensity and distribution of rainfall.

Of necessity, the erosion experiment stations were limited to small farm units of about 200 acres. Further limitations in funds and personnel reduced the size of the individual investigations to areas ranging in size from a fraction of an acre to 4 or 5 acres. On these experimental areas, and within a comparatively short period, a number of rainfall and run-off observations have been made, many of which show marked contrasts in run-off and soil loss under various surface treatments and cover.

The usefulness of these data is definitely limited, for the following reasons: First, the period is not sufficiently long to have embraced the full range of all the factors influencing the result; second, there are comparatively few cases in which run-off has been observed under unusually excessive rainfall; and third, the experimental areas are so small that the results cannot be considered as having areal significance. It is the purpose of this paper to present and demonstrate a method which, in a practical degree, may be used to overcome the latter limitation.

Engineers, and others, will be interested in the results obtained at the several erosion experiment stations, here presented only as observed hydrologic data. Figures 26 to 32 show rainfall and the resulting hydrographs of run-off wholly as basic data, without interpretation and accompanied only by a description of the conditions under which the observations were made. In this form it will be seen that there are very obvious differences in run-off rate and amount from areas covered by forest or sod when compared with run-off from a row-crop such as corn, both the result of the same rainfall. Likewise, the retarding effect of an increasingly flattening terrace slope is to be noted in the data. The whole story is not told, however, in the plotted graphs of rainfall and run-off, for back of each experience, and yet to be evaluated, are the effects of a multiplicity of antecedent influences, differences in soil type, the relative density of the respective plant canopies, varying rainfall rate and distribution, and the effect of inherent physiographic differences of the experimental areas themselves.

The plans of the Soil Conservation Service embrace a program of research which is intended ultimately to make possible, on an areal basis, the quantitative analysis of the many factors known to influence run-off. In the meantime, there is urgent need for such information as we now have. Obviously, a result obtained on seven-tenths of an acre, or 7 acres, cannot be extrapolated to 700 acres by means of simple multiplication. It is believed, however, that resorting only to well-established hydraulic assumptions, a method of combining and routing flow makes possible the projection of the results on these small areas to larger areas in the form of natural watersheds. The advantages to be gained from such a procedure are many. Run-off coefficients may be developed for use on areas of several hundred acres. The relative effectiveness of any combination of land use or cover may be quantitatively determined. The effect of varying the position of a particular land use or cover on the watershed may be studied quantitatively. The method may also be used to determine the effect upon the hydrograph of storage behind small dams.

The method here introduced subdivides the watershed into elemental units which are comparable in size to the observational areas found on the erosion experimental stations. It then develops the hydrograph of flow at various points on the stream system and at the outlet of the watershed by combining and routing the flow from each of the elemental units, assigning to each the hydrograph of flow from a particular experimental area, all the result of an actual rainfall. This, in effect, assumes that the conditions on the elemental unit, and those on the experimental area whose hydrograph it has been assigned, are identical.

The study has utilized a synthetic watershed

of rather simple outline and stream arrangement. The elaborateness of such a watershed, and the degree to which it is made to approach a particular natural watershed, are limited only by the time and work which the study may justify.

Figure 13 presents the synthetic watershed used in this study. It is made up of 128 elemental units of 5.7 acres each, making the area of the watershed about 730 acres. The stream system, while necessarily simple in pattern, is based upon assumptions of slope, channel dimensions, and channel condition which normally would fit a watershed of equivalent area and for which an approximate counterpart could easily be found in nature.

The "checkerboard" effect of the symmetrical subdivisions of the synthetic watershed is not so artificial as it would first appear when agricultural watersheds are considered. The subdivision of a region into farms superimposes upon the natural drainage system a secondary system of collection drains comprised of road and fence-line ditches, field drains, terraces, and crop furrows. Figure 14 is the aerial photograph of a typical agricultural area.

The first basic assumption is that, (*a*) the watershed is comprised of units identical in every respect with the particular experimental area or areas to be studied, except in size and shape; that, (*b*) to the extent of the area of the elemental unit (5.7 acres), run-off may be reduced to the common base of cubic feet per second per acre; and that, (*c*) the influence on run-off of the differences in shape of the individual units is compensative throughout the whole of a natural watershed and the net effect unimportant; in fact, each elemental unit of the synthetic watershed could be different in size and shape and even made to conform to particular experimental areas without violating the assumptions upon which the method is based.

The transition of water from rainfall, through surface run-off, to stream flow is so complex as to defy detailed quantitative analysis. With the beginning of rainfall at light or moderate intensities, all precipitation enters the ground for the period that the rainfall rate has been less than the infiltration capacity of the soil. Beyond that rate the excess promptly fills the irregularities of the ground surface and, by a progressive overflowing, initiates the march of the run-off sheet toward the stream channels. Under a continuing rainfall it is usually not long before a continuity of flow is established throughout the whole of the stream system, extending beyond the headwater channels as miniature drainage patterns.

Run-off water, as it reaches the principal stream channels, may be considered as being in temporary storage, the contributions to which are the inflow of the tributaries and the run-off from areas adjacent to the channels; and the withdrawal, the stream discharge at the outlet of the watershed. Under such circumstances the water cannot travel down the channels as uniform flow, nor can its rate of travel be taken as the average velocity fixed by the conditions of uniform flow. In reality, stages throughout the stream system are established by a translatory wave, the configuration of which continually changes as the increments of lateral flow reach and combine with that in the channels.

The second assumption, therefore, upon which the method is based is that the initial hydrographs assigned to each of the elemental units shall be combined and routed through the stream system timed by wave velocity and not the average velocity of uniform flow.

Our present knowledge of wave velocity cannot be more clearly summarized than in a statement by LeRoy K. Sherman,[2] as a discussion of the paper Translatory Waves in Open Channels, by Prof. Horace W. King:

[2] Letter to the editor of *Civil Engineering* from L. K. Sherman discussing a paper by H. W. King, *Civil Engineering*, August 1933, p. 483. See also, Experiments on the Effects of Upper Channel Improvements Upon the Downstream Flood Heights, by L. K. Sherman, *Journal of the Western Society of Engineers*, vol. XXVIII, August 1923, p. 293; and Discussion of Paper by Harold A. Thomas, p. 312.

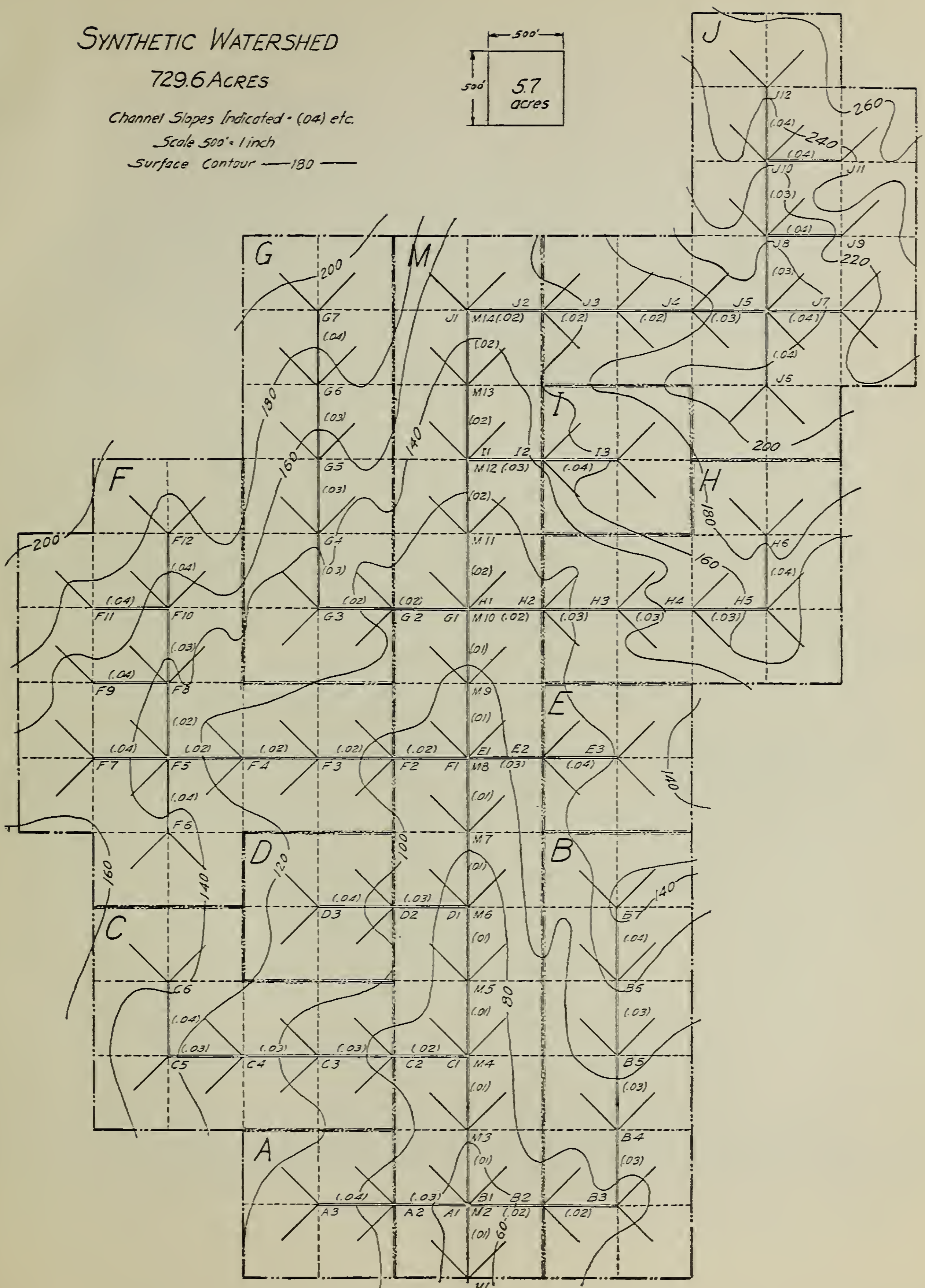

SYNTHETIC WATERSHED
729.6 ACRES
Channel Slopes Indicated • (04) etc.
Scale 500' = 1 inch
Surface Contour —180—
500'
500'
5.7
acres
G
M
F
J
I
H
E
D
B
C
A

FIGURE 13.

After making various experimental studies and investigations, I have arrived at certain conclusions on the subject of translatory waves moving downstream, and subject to channel friction. These are as follows:

1. The Seddon formula—$u=\frac{Q_2-Q_1}{A_2-A_1}$ correctly represents the wave velocity after the wave is formed.

2. During the period of formation of a wave due to a sudden increment, Q_2-Q_1, the mean velocity of advance of the toe of the forming wave is about 1.4 u.

3. If the stage-discharge curve and stage-area relation for a reach of a channel are known, the wave velocity for any increment of discharge at any stage is readily determined.

4. For a given increment of flow in a given channel, the wave velocity increases with the stage. At high stages the wave velocity u approaches a constant.

5. At high stages the wave velocity u is from 40 to 100 percent greater than the mean velocity V_2 of the water flowing in the channel upstream from the wave crest.

6. Under a sustained increment of flow the water surfaces D_2 and D_1, (the depths of normal flow) above and below the wave remain constant.

7. If the increased flow stops, the water surface behind the wave crest falls to the original flow line. The velocity of the tail of the wave decreases to the original velocity of the stream, while the crest of the wave, tends to advance with the original velocity—

$$u=\frac{Q_2-Q_1}{A_2-A_1}$$

The lag of the tail results in a gradual elongation accompanied by a corresponding gradual decrease in the height of the sustained wave. This unsustained type of wave is the one commonly observed in hydrographs of run-off in natural streams.

8. The front of the wave is not vertical. It is a relatively flat slope. The bulk of the volume of the wave front is included in a parabola, convex upward, and tangent to the flow line at the crest of the wave. A minor volume of the front or toe of the wave is included below a curved water surface, concave upward, tangent to the downstream flow line and the parabola. The length and shape of the wave can be computed. The phenomena and laws relating to translatory waves in stream channels apply to the forecasting of river stages and floods, and the time effect in river regulation from storage or water-power reservoirs. The time of transit is commonly computed from stream velocity when wave velocity u should be used. This applies to the derivation of the time of concentration. In applying the storage equation, inflow = outflow $\pm$ storage, to the computation of run-off from rainfall, I failed to meet the obvious requirements of this equation when stream velocities were used. Finally, however, by substituting wave velocity for water velocity, I obtained results that met the storage equation exactly. In general, wave velocity applies to all cases of rising stage or nonuniform flow in open channels.

It is not the purpose of this paper to undertake the analysis of wave velocity, or to develop methods for its determination, but to draw upon previous studies for the means of timing the progressively accumulating flows through the various reaches of the channel system.

In the Seddon formula,[3] to which Mr. Sherman refers, (Q_2, A_2) and (Q_1, A_1) are the discharges and cross-sectional areas at the upper and lower ends of a channel reach of definite length. Upon these values, at any instant, depend the instantaneous changes in the configuration of the flood wave within the reach. Also, at any instant, there exists somewhere within the reach, but not necessarily at its center, a section representing average channel characteristics of the reach and at which the average wave velocity is the same as that given by the equation,

$u=\frac{Q_2-Q_1}{A_2-A_1}$. The points (Q_2, A_2) and (Q_1, A_1) are found to define a secant to the Q–A curve of the average section (a plotted curve of normal discharge and cross-sectional area), the slope of which is wave velocity u. According to the theorem of the mean value, there exists a point on the Q–A curve at which the tangent is parallel to the secant so established. The slope of this tangent, then, may be taken as the average wave velocity through the reach under the particular conditions of inflow and outflow represented by Q_2 and Q_1.

In translating an entire hydrograph through a reach, each discharge on the hydrograph is considered as an independent traveling crest which, in passing through the average section, becomes the mean (Qav), of the unknown instantaneous discharges, Q_2 and Q_1, at the upper and

[3] River Hydraulics, by James A. Seddon, *Proceedings American Society of Civil Engineers*, October 1899, vol. XLIII, 1900, p. 179.

U. S. Soil Conservation Service photo.

FIGURE 14.—Air view of a representative agricultural area showing how the utilization of land for various purposes establishes a drainage pattern to which the assumed pattern of the synthetic watershed in figure 13 is similar.

FIGURE 15.

Experimental plat in Schuyler County, New York.

FIGURE 16.

Experimental plat at Page, Iowa.

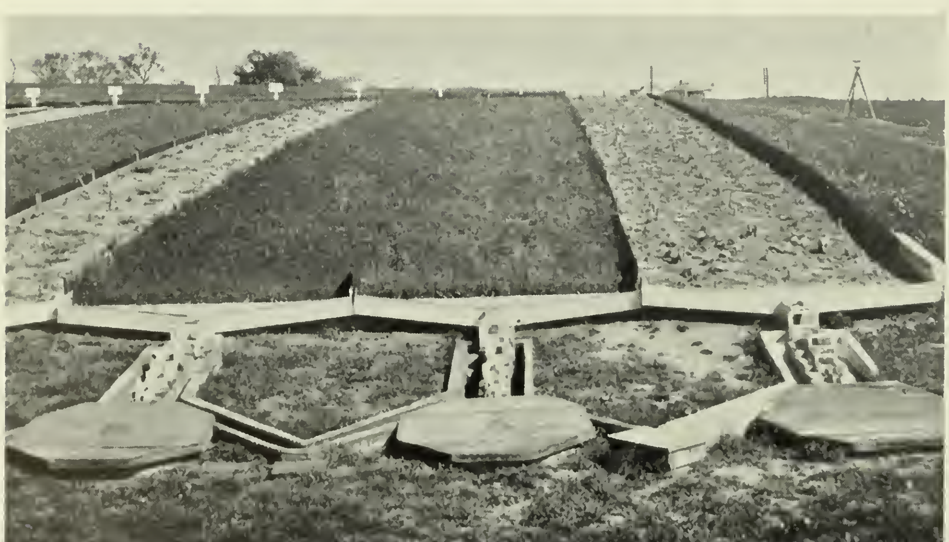


FIGURE 17.

Experimental plat at Bethany, Mo.

REPRESENTATIVE SOURCES OF UNIT DATA.

U. S. Soil Conservation photos.

lower ends of the reach respectively, the slope of the tangent to the Q–A curve being accepted as the slope of the secant fixed by these unknown limits. The approximate average wave velocity thus determined approaches the actual average as the slope of the tangent approaches a parallel with the secant established by the Q_2, Q_1 values, of which Qav is the instantaneous average.

Figure 18 shows the Q–u curves used in this study. These curves, as well as the Q–A curves from which they are derived are quite flat, indicating that the tangents to the Q–A curves closely parallel the secants for a considerable range in instantaneous discharges in and out of the reach.

The construction of the Q–A, Q–u, and Q–t curves are briefly described. Should a natural watershed be selected for study it is probable that a separate timing curve would be required for each reach of channel. If a synthetic watershed is made to represent a particular watershed, or the composite of a region, a plot of channel characteristics against drainage area above the section will prove helpful in classifying the reaches and reducing the number of timing curves to a minimum. In the synthetic watershed of the example the channels have been so sized as to require six timing curves, the channel characteristics being shown in figure 18. Using timing curve *c* to illustrate, the computations for the development of the curves are given in table 3.

TABLE 3

	Feet
Bottom (b)	5
Depth (d)	5
Top	20

Side slope, 1½ to 1.
Channel slope factor s, 0.02.
Roughness coefficient n, 0.04.
$P=b+3.6d$.
$A=(b+1.5d)d$.
$R=A/P$.

$$K=\frac{1.486\sqrt{s}}{n}=\frac{1.486\sqrt{0.02}}{0.04}=5.25$$

d	b	A	P	R	$R^{2/3}$	KA	$Q=KAR^{2/3}$
0.25	5	1.345	5.9	0.228	0.373	7.05	2.63
1.00	5	6.50	8.6	0.755	0.830	35.45	29.50
2.00	5	15.00	12.2	1.310	1.120	84.00	99.60
3.00	5	28.50	15.8	1.805	1.480	155.50	230.00
4.00	5	44.00	19.4	2.260	1.720	240.00	413.00
5.00	5	62.50	23.0	2.720	1.950	341.00	665.00

TABLE 4

Wave velocity curve					
a	*b*	*c*	*d*	*e*	*f*
Channel reach					
A3–A2	A2–A1	B2–B1	M14–M13	M10–M9	M6–M5
B7–B6	B6–B5	C2–C1	M13–M12	M9–M8	M5–M4
C6–C5	B5–B4	F4–F3	M12–M11	M7–M6	M4–M3
D3–D2	B4–B3	F3–F2	M11–M10		M2–M1
E3–E2	C5–C4	F2–F1			
F12–F10	C4–C3	G2–G1			
F11–F10	D2–D1	H2–H1			
F9–F8	E2–E1	J4–J3			
F7–F5	F10–F8	J3–J2			
F6–F5	F8–F5	J2–J1			
G7–G6	F5–F4				
H6–H5	G6–G5				
I3–I2	G5–G4				
J12–J11	G4–G3				
J11–J10	H5–H4				
J9–J8	H4–H3				
J7–J5	I2–I1				
J6–J5	J10–J8				
	J8–J5				
	J5–J4				

The Q–u curve is taken directly from the Q–A curve by successively measuring the slope of the tangents to the curve, and plotting the values against discharge Q. The Q–t curve is the plotted conversion of wave velocity to time in minutes through a length of reach of 500 feet. These curves are displayed in figure 19. The reaches to which the respective curves are assigned are given in table 4.

One of the recent works embracing the theory of flood-wave propagation is that of Prof. Harold A. Thomas.[4] It is shown that the creation and translation of the wave is a continual adjustment of the storage equation, Inflow=Outflow± Change in Storage. A hydrograph translation through a series of reaches by the "Q–A curve-tangent" method is found to agree reasonably in time position with that resulting from the "second approximate method" presented by Professor Thomas. The former method, while admittedly less accurate, accomplishes the timing with only a fraction of the labor involved in the latter. Such an expedient as the Q–A curve-tangent method has made practicable this study which combined and routed several hundred hydro-

[4] *The Hydraulics of Flood Movements in Rivers*, Bulletin of Carnegie Institute of Technology, 1934, p. 17.

WAVE VELOCITY CURVES

	CHANNEL CHARACTERISTICS					
CURVE	BOTTOM	TOP	DEPTH	SIDE SLOPE	BOTTOM SLOPE	ROUGHNESS COEFICIENT
a	3 FT.	12 FT.	3 FT.	1 1/2-1	0.04	0.04
b	4	16	4	1 1/2-1	0.03	0.04
c	5	20	5	1 1/2-1	0.02	0.04
d	6	24	6	1 1/2-1	0.02	0.04
e	8	32	8	1 1/2-1	0.01	0.04
f	9	36	9	1 1/2-1	0.01	0.04

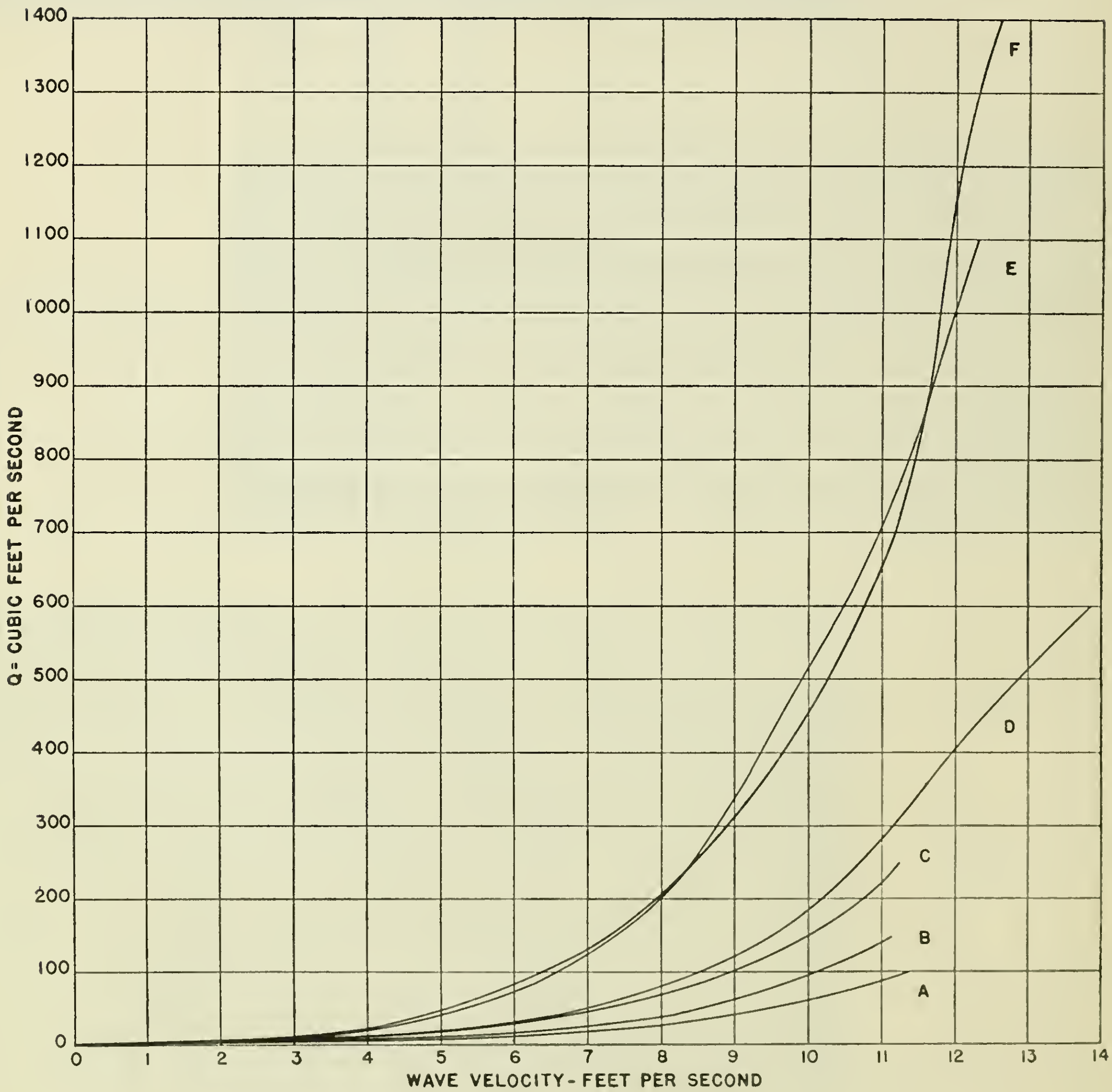


FIGURE 18.

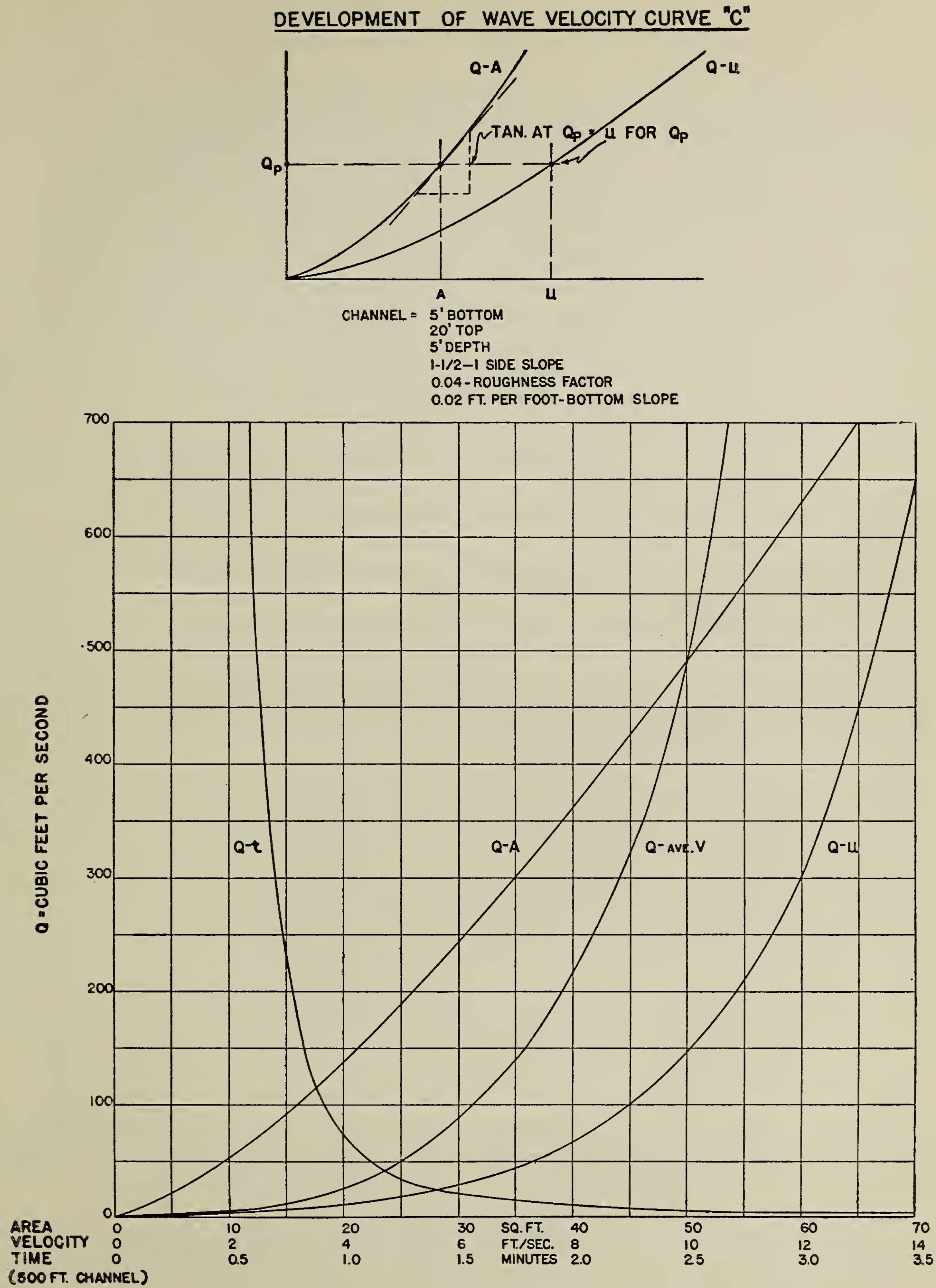

DEVELOPMENT OF WAVE VELOCITY CURVE "C"
Q-A
Q-u
TAN. AT Qp = u FOR Qp
Qp
A
u
CHANNEL = 5' BOTTOM
20' TOP
5' DEPTH
1-1/2—1 SIDE SLOPE
0.04-ROUGHNESS FACTOR
0.02 FT. PER FOOT-BOTTOM SLOPE
Q = CUBIC FEET PER SECOND
0
100
200
300
400
500
600
700
Q-t
Q-A
Q-AVE.V
Q-u
AREA 0 10 20 30 SQ.FT. 40 50 60 70
VELOCITY 0 2 4 6 FT./SEC. 8 10 12 14
TIME 0 0.5 1.0 1.5 MINUTES 2.0 2.5 3.0 3.5
(500 FT. CHANNEL)

FIGURE 19.

graphs through approximately 60 reaches of the synthetic stream system.

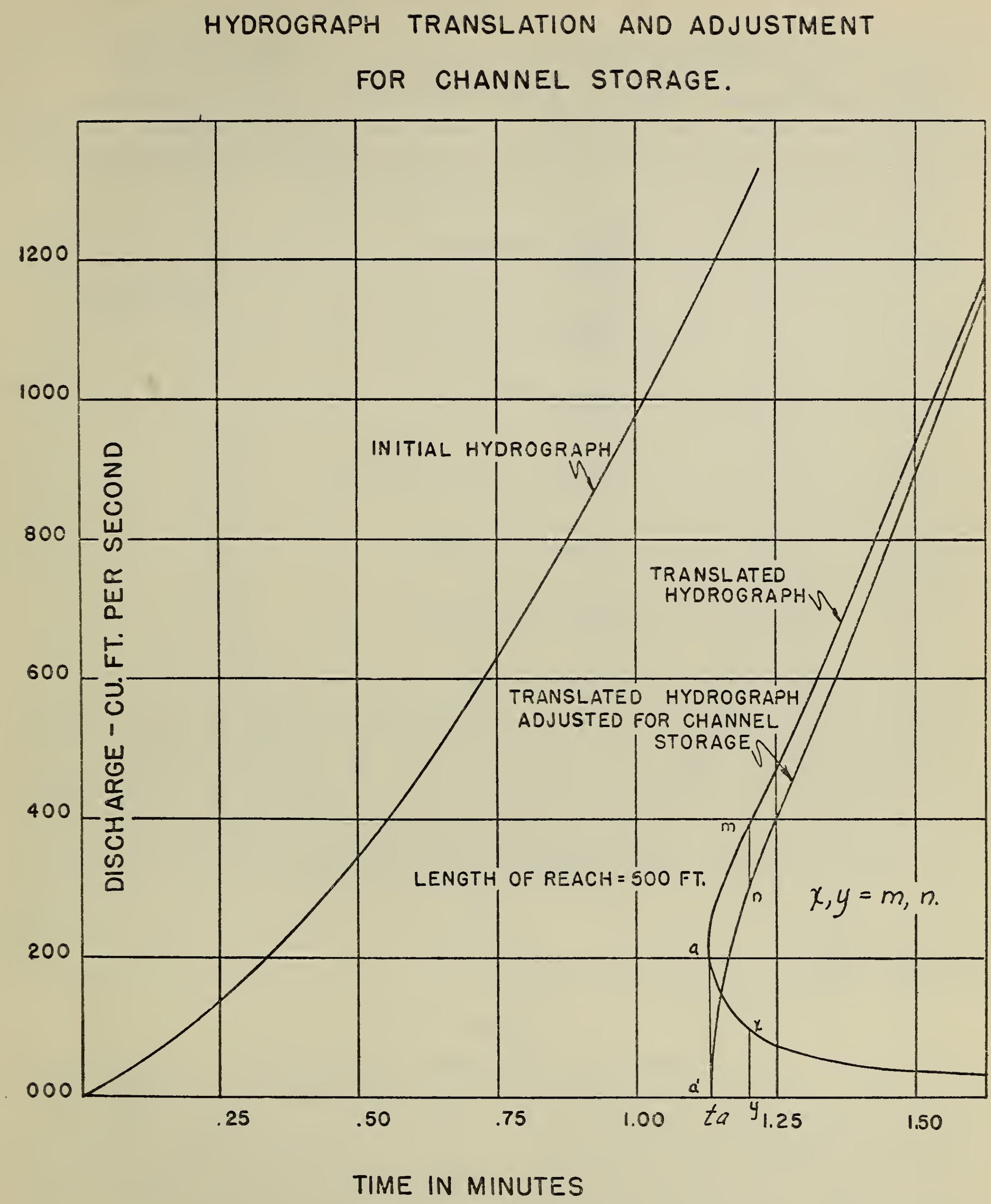
The first water discharging into a dry channel reach enters at comparatively low velocity. It is soon overtaken and combines with the increasingly greater flows traveling at faster rate so that, for an initial period, there is no outflow from the reach, all of the water going into storage. Likewise, at the end of the period of flow, water will have ceased to enter the reach while the amount occupying storage continues to discharge. If the lower values of the hydrograph are translated through the reach with their appropriate wave velocities, the translated hydrograph is made to turn under itself, as shown in figure 20. The only significance given to this peculiarity is to assume that all of the water discharging into the reach throughout the time interval t_o, t_a, has accumulated into a wave-face resembling a hydraulic bore and at t_a instant arrives at and discharges into the reach below. A correction in the shape of the outflow hydrograph for the effect of channel storage is made by bringing point a to the time-base as zero flow, and deducting the successive ordinates of the underturned portion of the hydrograph from the corresponding ordinates of the normally rising hydrograph above it. The lower velocities of the lessening flows of the falling hydrograph add an equivalent area to the hydrograph at the end of the period of flow into the reach, accounting for the water originally discharged into storage. If a hydrograph is translated through successive reaches of dry channel in this manner it will be found that these deductions will soon extend to and beyond the peak, reflecting the recognized influence of storage on peak flow. In problems involving small natural watersheds and the rapid occupation of storage through simultaneous inflow at all points on the stream system, this correction is not great, but should be made principally to avoid the accumulative error in adding the ordinates of the combining hydrographs.

In order to explain and demonstrate the practical usefulness of the flow-routing method, let us assume that the synthetic watershed as shown in figure 13 is the composite of the region in the vicinity of the erosion experiment station at Bethany, Mo.; that is, the channel slopes, channel dimensions, and the channel roughness factor n are typical of natural watersheds of about 700 acres in that locality. We now have a framework upon which to assemble a watershed surface made up of the surface slopes, soils, vegetal cover, and surface treatment prevailing upon the experimental areas selected for study, as these factors are reflected in the hydrographs of run-off.

The next step in the procedure is developing for each channel-reach of like hydraulic elements its Q–t curve, as previously described.

Having the synthetic watershed in figure 13 and the timing curves in figure 18, we are prepared to compare and evaluate, in terms of stream flow, any of the combinations under study at the Bethany station for which there is an observed rainfall and run-off. Hydrographs H4 and H5, shown in figure 26, are selected to demonstrate the method, H4 being an area bounded by a terrace and with a grass cover, and H5 an adjacent area on which there was a crop of growing corn, cultivated with the contour. The figure shows the rainfall of August 9, 1933, both in rate and cumulative amount. It also shows the hydrographs of run-off from the various experimental areas, descriptions of which accompany the graphs in the figure. The areas of H4 and H5 are 1.251 acres and 1.237 acres, respectively. Each elemental unit of 5.7 acres, therefore, is considered to yield 4.6 times the run-off rate shown in the figure under the assumption previously given that within areas of 5.7 acres, where the combination and synchronization of run-off involves a negligible time interval, the direct combination of flow is permissible.

Again it is noted that this study does not attempt to explain the difference in the two selected hydrographs. It assumes only that, for



HYDROGRAPH TRANSLATION AND ADJUSTMENT
FOR CHANNEL STORAGE.
DISCHARGE - CU. FT. PER SECOND
1200
1000
800
600
400
200
000
INITIAL HYDROGRAPH
TRANSLATED
HYDROGRAPH
TRANSLATED HYDROGRAPH
ADJUSTED FOR CHANNEL
STORAGE
LENGTH OF REACH = 500 FT.
m
n
a
x
a'
x, y = m, n.
.25
.50
.75
1.00
ta
y
1.25
1.50
TIME IN MINUTES

FIGURE 20.

the elemental unit to which the sod hydrograph is assigned, the conditions are the same as those of the experimental area H4 on August 9, 1933, and for those areas assigned the corn hydrograph, the conditions are the same as were found on experimental area H5 on that date. area H5 is the sample. These hydrographs are presented in figure 21.

The procedure is to develop the hydrographs at the outlet of each of the laterals, after which the flow is assembled throughout the length of the main channel.

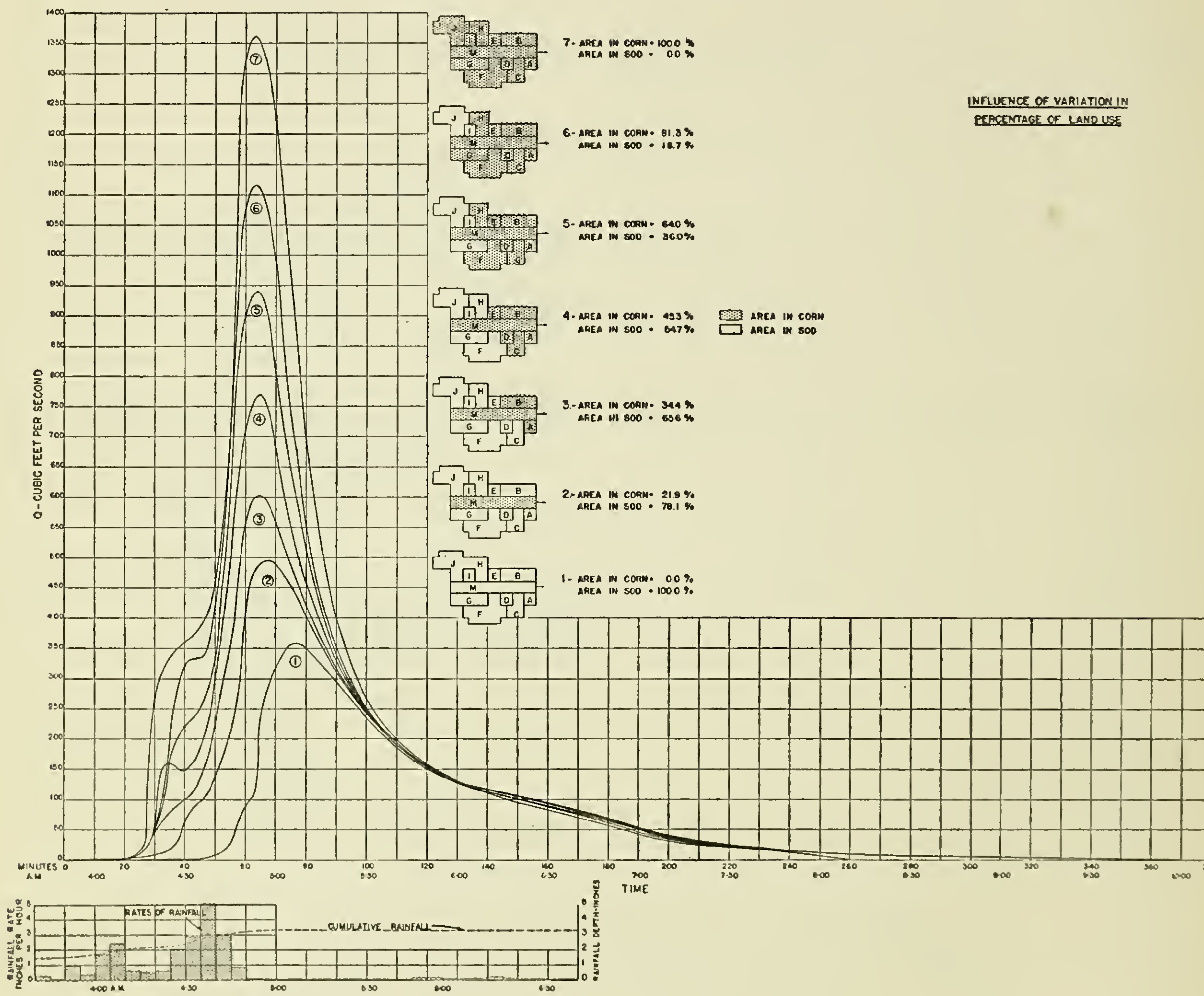
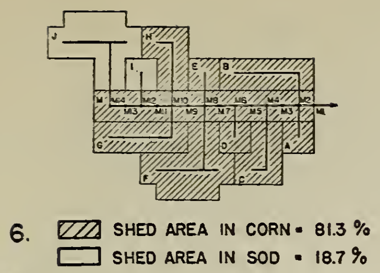


Figure 21.

This study now proposes to determine, in the form of hydrographs of flow at the outlet of the 730 acre watershed, the effect on the hydrograph of progressively passing from the assumption that the entire watershed is covered by sod, as experimental area H4, to that under which it is entirely covered by the corn crop, of which experimental

After initial hydrographs have been assigned to the elemental units, routing schedules are prepared for each of the laterals as illustrated in table 5. The routing schedule for the main channel is displayed in figure 22, indicating each step of the procedure and organizing an orderly and systematic assembly of flow.



ROUTING SCHEDULE				
JUNCTION POINT	INTERMEDIATE POINT	OPERATION	RESULTANT	QUANTITY IN CUBIC FEET
M14		J2Bs+2Δc ——→ T_C*	M14B	228,000 J2BS 54,000 2ΔC 282,000 M14B
	M13	M14B+2Δc ——→ T_C	M13B	54,000 2ΔC 336,000 M13B
M12		M13B+2Δc+I2Bs ——→ T_D	M12B	54,000 2ΔC 45,600 I2BS 435,600 M12B
	M11	M12B+2Δc ——→ T_D	M11B	54,000 2ΔC 489,600 M11B
M10		M11B+2Δc+H2Bc+G2Bc ——→ T_E	M10B	54,000 2ΔC 270,000 H2BC 324,000 G2BC 1,137,600 M10B
	M9	M10B+2Δc ——→ T_E	M9B	54,000 2ΔC 1,191,600 M9B
M8		M9B+2Δc+E2Bc+F2Bc ——→ T_E	M8B	54,000 2ΔC 108,000 E2BC 540,000 F2BC 1,893,600 M8B
	M7	M8B+2Δc ——→ T_E	M7B	54,000 2ΔC 1,947,600 M7B
M6		M7B+2Δc+D2Bc ——→ T_F	M6B	54,000 2ΔC 108,000 D2BC 2,109,600 M6B
	M5	M6B+2Δc ——→ T_F	M5B	54,000 2ΔC 2,163,600 M5B
M4		M5B+2Δc+C2Bc ——→ T_F	M4B	54,000 2ΔC 270,000 C2BC 2,487,600 M4B
	M3	M4B+2Δc ——→ T_F	M3B	54,000 2ΔC 2,541,600 M3B
M2		M3B+2Δc+A2Bc+B2Bc ——→ T_F	M2B	54,000 2ΔC 108,000 A2BC 324,000 B2BC 3,027,600 M2B
	M1	M2B+2Δc ——→	M1.	54,000 2ΔC 3,081,600 M1

ADDITION AND TRANSLATION, WITH "Q-T" CURVE "C" = T_C*, ETC.

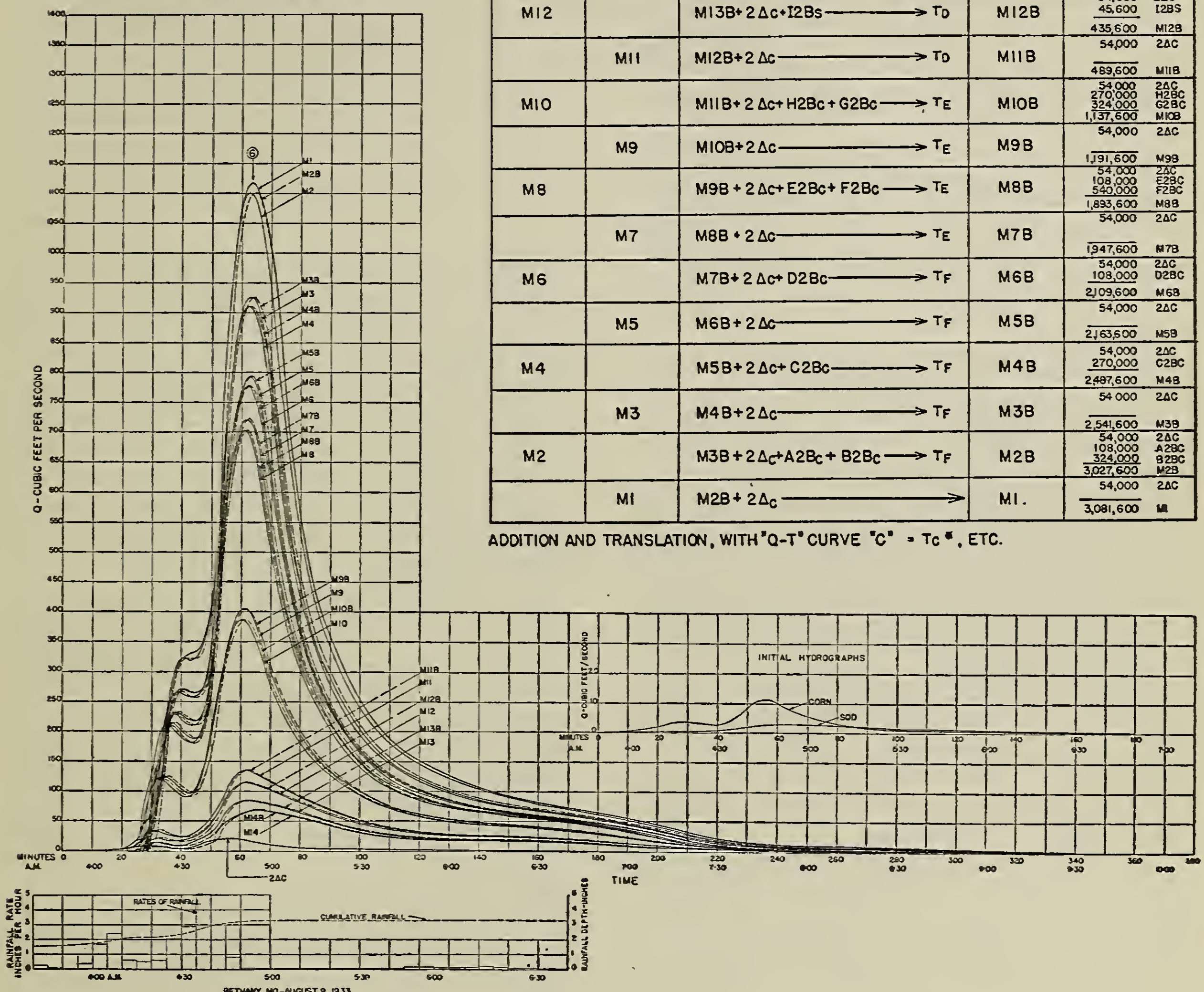


FIGURE 22.

Illustrative Example of Combination and Routing of Stream Flow.

The symbol Δ designates an initial hydrograph, and the subscript identifies it with the particular experimental area of which it is representative. Thus, Δ_s is the initial sod hydrograph, and Δ_c the initial corn hydrograph.

The symbol $\rightarrow T_a$ represents the hydrograph translation. The subscript "a" refers to the timing curve for the particular reach through which the translation is to be made, as given in table 5.

The suffix "B" is assigned to the hydrograph to denote its translation. Thus, the hydrograph C3 becomes C3B after it has been translated through the reach C3–C2. At this point it combines with other flow to become hydrograph C2.

Both rainfall and run-off are referred to the same chronological time-base so that the synchronization of flow is accomplished minute by minute throughout the period of run-off.

While the combination and routing could be done analytically by an elaborate system of listing and tabulation, it is believed that the graphical method proposed is far more economical in both time and paper. It has been found best to plot the initial hydrographs, as well as their combinations, on transparent coordinate paper, using a sharp, hard pencil. The selection of a proper scale is a compromise between that large enough to reduce to a minimum the normal error involved in plotting, and that small enough to permit the display of the final hydrographs on sheets of reasonable dimension. Where outflow peaks are not greatly in excess of 1,500 cubic feet per second, a scale of 20 cubic feet per second per inch of ordinate is practical.

It is found advisable to trace each translated hydrograph on to a new sheet before proceeding with further combinations, carefully adjusting each new sheet to the time base of sheet 1.

The steps in flow routing for lateral C (or lateral H) when in corn are as follows:

Step 1. The routing schedule is prepared as shown in table 5.

Table 5.—*Routing schedule, lateral C*

Junction point	Intermediate point	Operation	Resultant	Quantity
	C6	$C6 \rightarrow T_a$	C6B	54,000 C6B 54,000 $2\Delta_c$
C5	--------	$C6B+2\Delta_c \rightarrow T_b$	C5B	108,000 C5B 54,000 $2\Delta_c$
	C4	$C5B+2\Delta_c \rightarrow T_b$	C4B	162,000 C4B 54,000 $2\Delta_c$
C3	--------	$C4B+2\Delta_c \rightarrow T_b$	C3B	216,000 C3B 54,000 $2\Delta_c$
	C2	$C3B+2\Delta_c \rightarrow T_c$	C2B	270,000 C2B

Step 2. The initial hydrographs for the two headwater elemental units of lateral C, being both in corn, are added graphically by doubling each ordinate, creating hydrograph C6.

Step 3. This hydrograph is translated by moving to the right a sufficient number of Q-values through a time interval, using timing curve "a" to define accurately the hydrograph in its new position, where it is corrected for channel storage and designated as hydrograph C6B.

Step 4. Hydrograph C6B is now traced on to sheet 2, to which are added the two initial hydrographs from the elemental units discharging into the channel at point C5. The resulting hydrograph is designated as C5.

Step 5. Hydrograph C5 is translated through reach C5–C4, as previously described, using timing curve "b", thus becoming hydrograph C5B.

This procedure, which is seen to be wholly mechanical after the routing schedule has been prepared, continues throughout the length of lateral C to its junction point with the main channel.

Having the hydrographs for each of the laterals, the assembly of flow on the main channel is but a continuation of the procedure which has been applied to the laterals. Figure 22 presents the development of hydrograph 6, taken from figure 21. Each step is given in the routing schedule. It is seen that at junction point M10 the assembled flow to be translated through

reach M10–M9 is that reaching the point from above as M11B, the flow from lateral G (hydrograph G2B), lateral H (hydrograph H2B), and the run-off from the elemental units adjacent to the reach.

The routing schedule also provides for a check on the quantity of water which each translated hydrograph represents. Obviously (assuming no losses in the channel system due to infiltration and evaporation and no ground-water recharge), the quantity of water remains the same before and after translation. The total quantity at any time is numerically equal to the sum of the quantities of water flowing from the elemental units above the point at which the hydrograph is being developed. The work should be periodically checked by comparing the planimetered areas under the hydrograph with the calculated quantity shown in the last column of the routing schedule. Differences of 1 percent from the calculated value were accepted for the lateral hydrographs, while 3 percent was the limiting error in defining the outflow hydrographs on the main channel.

The scope of this paper has not permitted more than an explanation of a method and a demonstration of its technique. The distribution by laterals only, of the two types of cover compared in the seven cases of figure 21, is not typical of agricultural regions. Farming areas are normally divided into small subdivisions, usually rectilinear, conforming somewhat to the pattern illustrated in figure 14. Considering the two cover crops compared in the demonstration as representing grassland or pasture, and row crops in general, a more normal distribution could have been gained by a fortuitous or deliberate disarrangement of the corn and sod units.

The effect of changing from corn to sod as measured by the reduction of the flood peak on the synthetic watershed of the example, under the conditions accompanying the rainfall of August 9, 1933, is shown in table 6.

TABLE 6

Hydrograph no.	Percent of area in sod	Percent reduction in peak	Hydrograph no.	Percent of area in sod	Percent reduction in peak
7	0	0	3	66	56
6	19	17	2	78	63
5	36	31	1	100	74
4	55	44			

The conclusion must be drawn that, on watersheds up to 730 acres at least, the peak-reducing value of an effective cover varies almost directly as the degree to which the watershed is represented by such cover. This is explained in part by figure 23. Here it is seen that there is practically no change in peak flow per acre for the entire watershed when completely under sod cover, accounted for by the fact that the broad, flat crest of the initial sod hydrograph prevailed and changed but little throughout the period that run-off was accumulating. On the other hand, the comparatively sharp peak of the corn hydrograph occupied too short a time interval to allow for complete synchronization of the lateral peak flows, with the result that the peak flow per acre reduced as distance and area were passed in the movement of the flood wave downstream. The figure also shows the change in the peak flow per acre as cover was changed from corn to sod, or vice versa.

Among the first demands upon hydrologic research is the development of run-off factors necessary in the design of hydraulic structures. A run-off coefficient is particularly needed for use in the determination of peak flow which is generally taken to be the ratio of peak flow, in cubic feet per second, to the average rainfall rate for the period of concentration.

Figure 23 shows the change in this ratio for both sod and corn as time, distance, and area are passed in progressing down the watershed. The same characteristics are exhibited in the run-off ratio as in the value of peak flow per acre with respect to the factors—time, distance, and area, as demonstrated in figure 24.

It is understood that we are here dealing with

INFLUENCE OF VARIATION IN POSITION AND PERCENTAGE OF LAND USE ON RUN-OFF COEFFICIENT

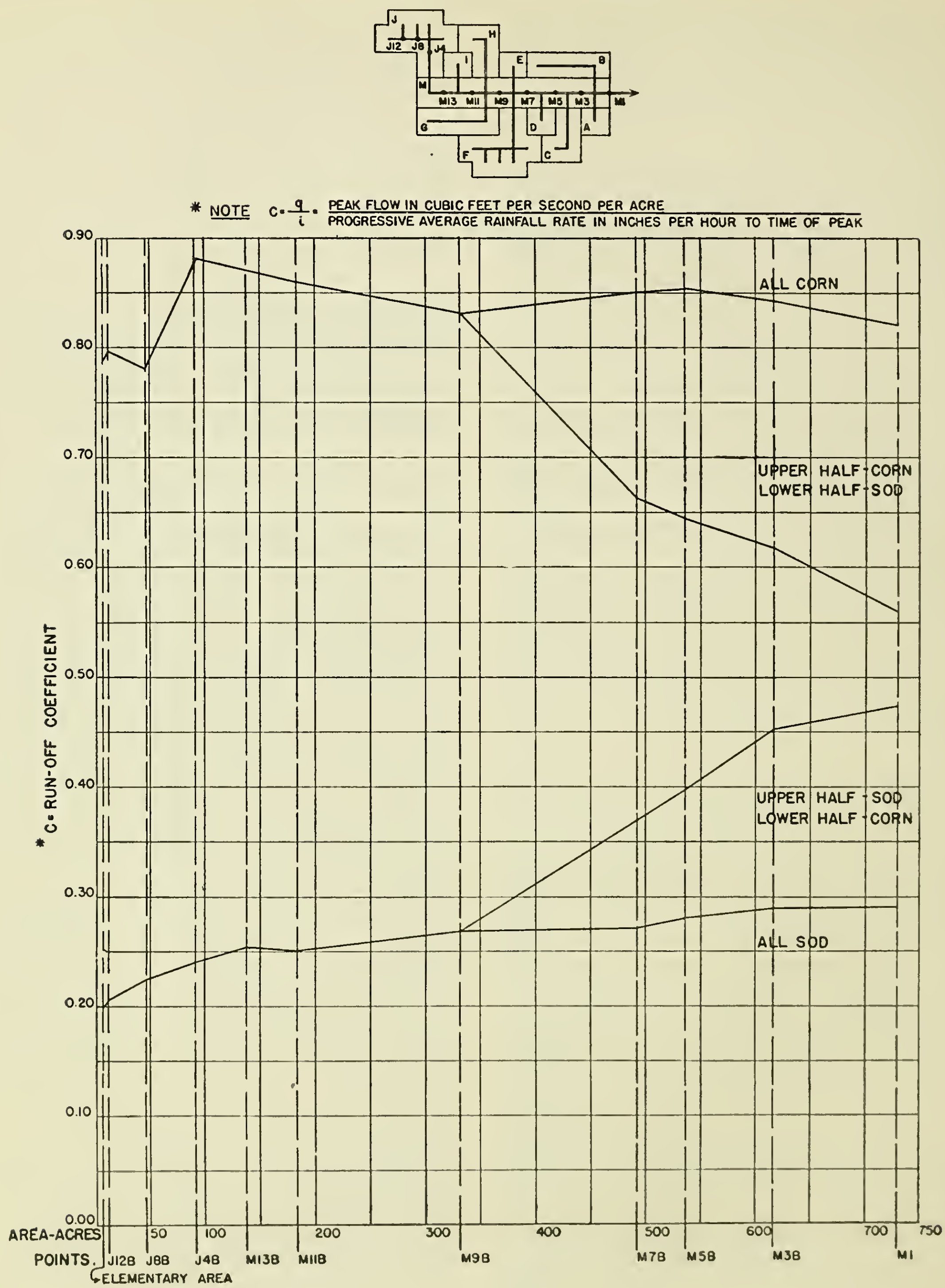


Figure 23.

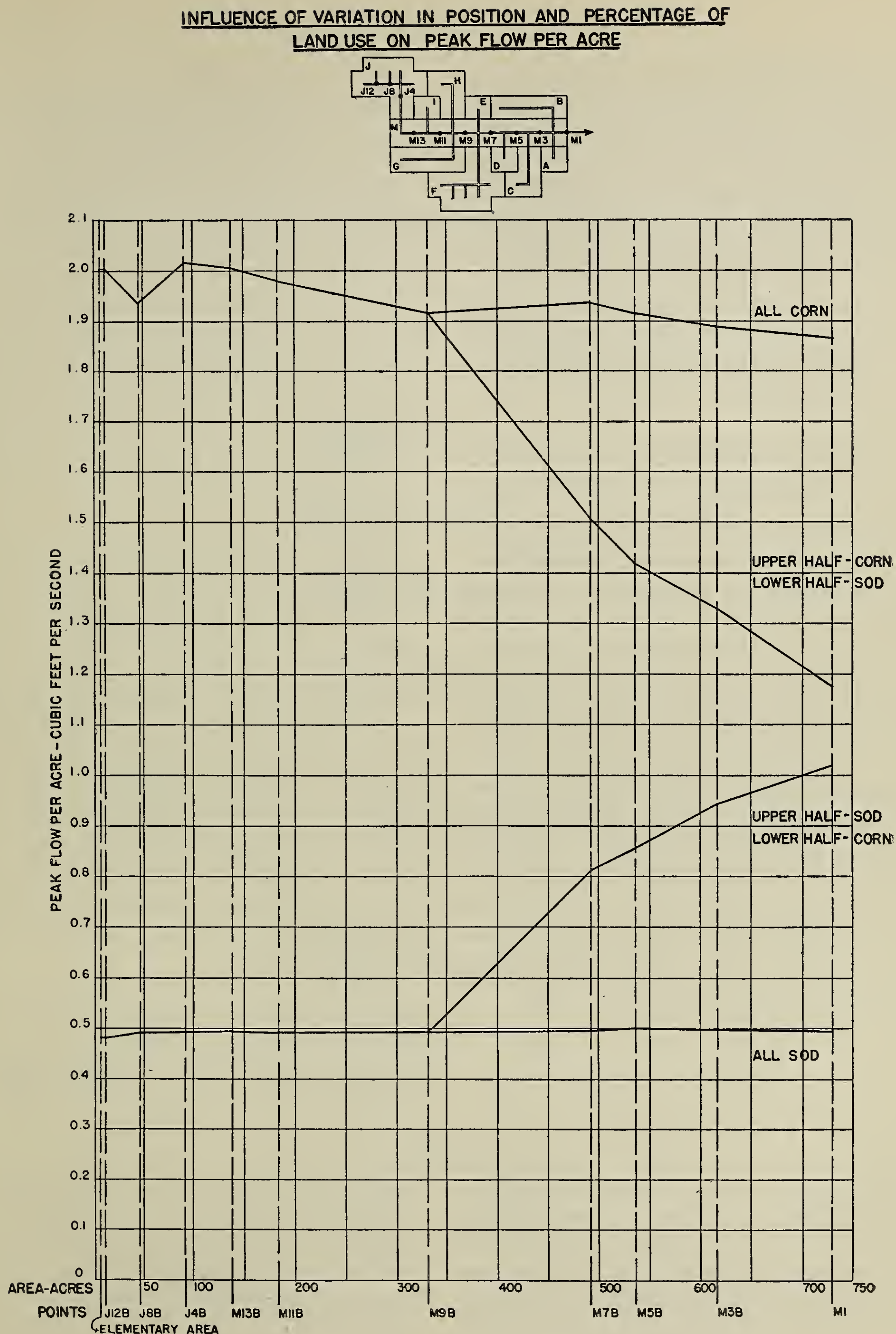

INFLUENCE OF VARIATION IN POSITION AND PERCENTAGE OF LAND USE ON PEAK FLOW PER ACRE
J
J12 J8 J4
H
I
E
B
M
M13 M11 M9 M7 M5 M3 M1
G
D
A
F
C
PEAK FLOW PER ACRE - CUBIC FEET PER SECOND
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ALL CORN
UPPER HALF - CORN
LOWER HALF - SOD
UPPER HALF - SOD
LOWER HALF - CORN
ALL SOD
AREA-ACRES
50
100
200
300
400
500
600
700
750
POINTS
J12B J8B J4B M13B M11B M9B M7B M5B M3B M1
ELEMENTARY AREA

FIGURE 24.

factors prevailing throughout a particular storm, and such factor values are not to be assigned to corn and sod, respectively, as measures of their effectiveness to retard or accelerate run-off. The run-off factor is known to vary with the intensity of rainfall, and the effectiveness of sod to delay run-off and prolong the period of infiltration can be expected to decrease as rainfall intensity increases. It is believed, however, that there will always be found a marked difference in the run-off-producing characteristics of such contrasting vegetal covers as grass, and row crops such as corn.

In utilizing the method for the development of run-off coefficients for this watershed, consideration should be given the fact that, while it is possible for a watershed of 730 acres to be planted entirely in corn or in sod, the possibility for such to occur in a permanently subdivided farming community is remote, particularly under modern conceptions of farm management.

It is commonly believed that flood peak reduction is accomplished through retardation only. To the degree that the shape of the watershed and the pattern of its stream system affects the synchronization of the various tributary flows is the regimen of the watershed reflected in the magnitude of its flood peaks. That the regimen of the watershed can be so affected as to accelerate the run-off from certain of its subareas, thereby reducing the peak by utilizing more completely the comparatively empty channel system during the rising stage of the hydrograph, is seldom considered.

This theory is demonstrated in figure 25. Here exactly one-half of the watershed is considered as being in sod and the other half in corn. Hydrograph "Y" has been developed under the assumption that the lower half is in corn and the upper half in sod. The heavier run-off from the corn is promptly discharged, filling out the rising stage of the hydrograph with flow that would otherwise have contributed to the peak flow, while the lesser and slower run-off from the sod units above are delayed until the peak has passed. Under the reverse assumption, that is, the lower half of the watershed in sod and the upper half in corn, hydrograph "X" is developed. Now the run-off from the lower half is retarded while that from the upper half has been accelerated, with the result that waters which otherwise would have been removed from the areas near the outlet before the peak arrived, are delayed until the more rapidly moving water from the corn above arrives and combines with it. The result is that, maintaining the same area in each type of cover and without changing the amount of run-off water involved, the flood peak can be affected to the extent of about 15 percent by virtue of the relative position of the cover types alone.

The expansion of the method to embrace problems on watersheds larger than 700 acres has interesting possibilities. Synthetic watersheds of 730 acres can be combined only to the point that the integrated area does not exceed that over which rainfall rates can be considered as evenly distributed. Beyond this limiting area the usefulness of the method could be enhanced by superimposing actual or synthetic storms upon the area, and assigning to each of the elemental units infiltration capacities and rates under conditions of rainfall comparable to those accompanying the superimposed storm, and under conditions of soil, cover, and land use prevailing on the experimental areas yielding the infiltration data.

Infiltration, now usually expressed as an empirical coefficient, is more logically considered as a deduction from rainfall in that it is actively removing water from the same area and with about the same distribution as water is being applied in the form of rainfall. The "net rainfall", or surface run-off, can then be related to the particular units of area which produced it.

The method also offers the means of studying and further developing the application of the unit-hydrograph method to small watersheds. The unit hydrograph is known to be an excellent tool in problems involving the determination of

run-off and streamflow from rainfall. Briefly, a unit hydrograph is that resulting from a rainfall of a unit-time duration, as an hour or day. Such hydrographs, for a particular watershed, are found to have the same time base, the ordinates varying with the intensity of rainfall and run-off. When the ordinates of a number of unit hydrographs for a watershed are reduced to percentage of total flow they are found to agree closely in base length, shape, and ordinate value. The average of a number of such graphs, called a "distribution graph", reflects the run-off producing characteristics of the watershed, and is the means of developing flood hydrographs from storm rainfall.

It would seem that the method of combining and routing flow presented in this paper takes fewer liberties with hydraulic laws than many model studies upon which extensive structures are designed. This, and other methods, are definitely limited in both development and application by the deplorable paucity in our knowledge of the hydrodynamics of natural stream flow. Despite this reflection, it is the hydraulic model which promises the prompt solution of such problems.

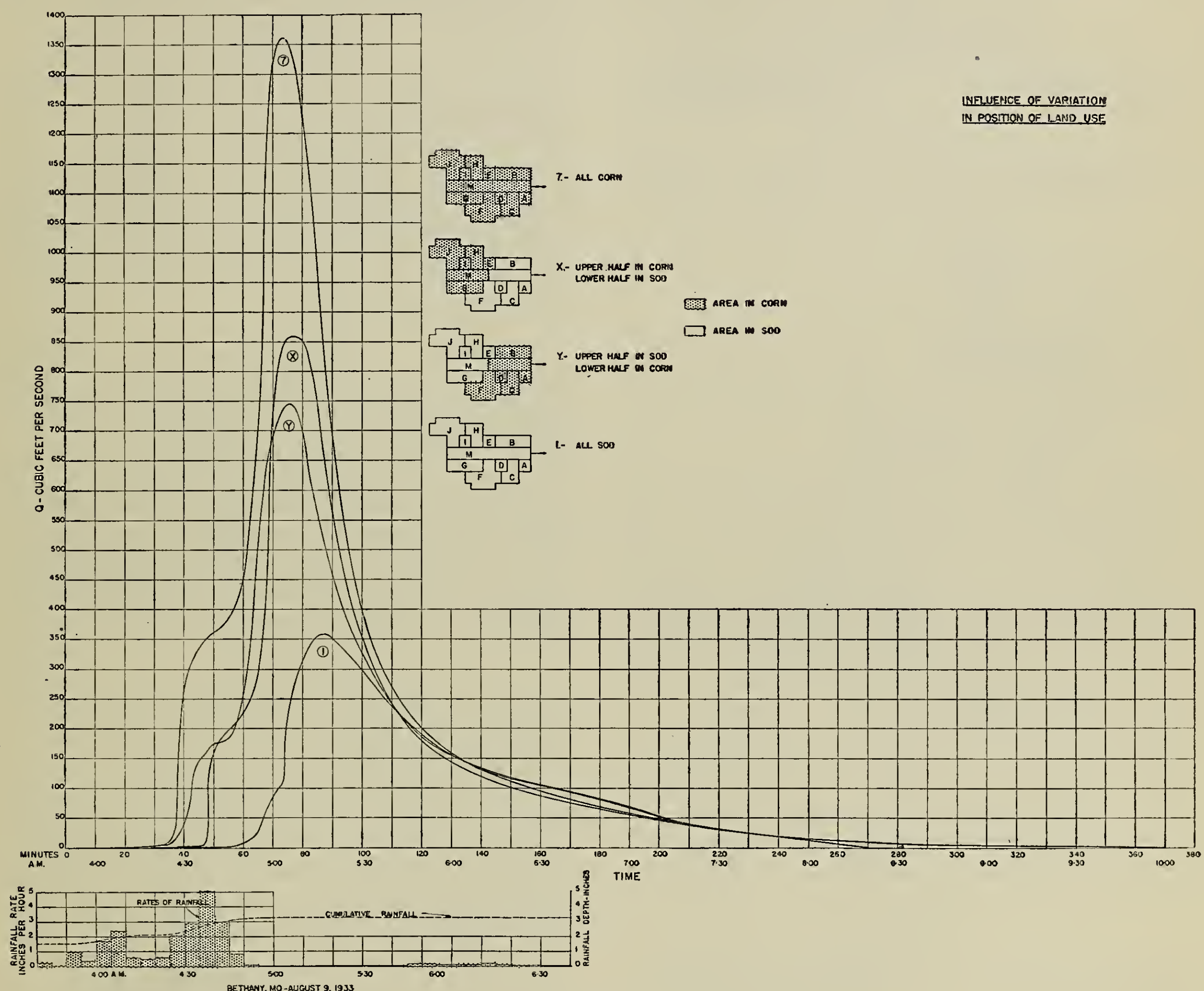
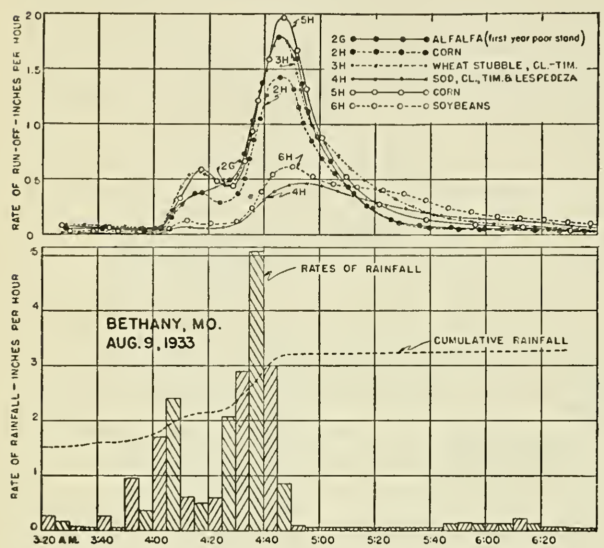


Figure 25.

ILLUSTRATIVE SPECIMEN HYDROGRAPHS FROM EROSION EXPERIMENT STATIONS

HYDROGRAPH OF AUGUST 9, 1933, AT BETHANY, MO.—FIGURE 26



Terrace 2–G

Character.—Alfalfa, first year; 0.75 acre drainage area; 12 percent average land slope.

Soil.—Shelby sandy loam soil; about 65 percent [5] of area shallow phase, 1 to 4 inches deep; 25 to 30 percent deep phase, 4 to 7 inches deep; 5 to 10 percent of subsoil exposed; consisting of tight, plastic clay with considerable sand and a little gravel. A large gully, 20 to 30 feet wide, 5 to 6 feet deep, extending full length of slope, was filled before terraces were constructed.

Cover, farm operations, erosion-control practices, etc.—Alfalfa was seeded in the spring and was just getting started at the time of the first heavy May rains. A poor stand of alfalfa was obtained, which no doubt accounts for the comparatively high run-off. Length of terrace 650 feet, vertical interval 6 feet, uniform grade of 4 inches per 100 feet.

Terrace 2–H

Character.—Corn, 1.46 acres drainage area; 8.3 percent average land slope.

Soil.—Practically the same as in terrace 2–G.

Cover, farm operations, erosion-control practices, etc.—Corn on contour followed sweetclover and oats on this area. Stand of corn was reduced due to chinch bugs. Considerable wild grass between corn rows. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

[5] Percentages are approximate.

Terrace 3–H

Character.—Wheat stubble; 1.41 acres drainage area; 8.5 percent average land slope.

Soil.—Practically the same as in terrace 2–G.

Cover, farm operations, erosion-control practices, etc.—This area was in wheat followed by clover and timothy, and at the time of this rain the cover was wheat stubble with clover and timothy. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

Terrace 4–H

Character.—Sod; 1.25 acres drainage area; 9.6 percent average land slope.

Soil.—Practically the same as in terrace 2–G.

Cover, farm operations, erosion-control practices, etc.—Second year meadow on this area, consisting of clover, timothy and lespedeza. Meadow made a heavy spring growth before this rain occurred. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

Terrace 5–H

Character.—Corn; 1.24 acres drainage area; 9.7 percent average land slope.

Soil.—Practically the same as in terrace 2–G.

Cover, farm operations, erosion-control practices, etc.—Corn followed wheat on this area. Corn was affected by chinch bugs but had attained a good growth at the time of this rain. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

Terrace 6–H

Character.—Soybeans; 1.23 acres drainage area; 9.8 percent average land slope.

Soil.—Practically the same as in terrace 2–G.

Cover, farm operations, erosion-control practices, etc.—Soybeans followed corn on this area, which were planted sometime in May. Soybeans were drilled in rows 8 inches apart. At time of this rain the plants had attained a good growth and furnished a complete cover. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level of 4 inches per 100 feet.

HYDROGRAPH OF SEPTEMBER 26, 1933, AT BETHANY, MO.—FIGURE 27

Area B

Character.—Bluegrass pasture; 6.52 acres drainage area; 9.5 percent average land slope.

Soil.—Seventy percent of area Shelby sandy loam, deep phase, 4 to 7 inches deep; 15 percent shallow phase, 1 to 4 inches deep; 5 percent colluvial material, 10 percent Grundy silt loam, 8 to 18 inches deep, underlayed by

pliable, porous clay loam; one-fourth of 1 percent of are is gullied.

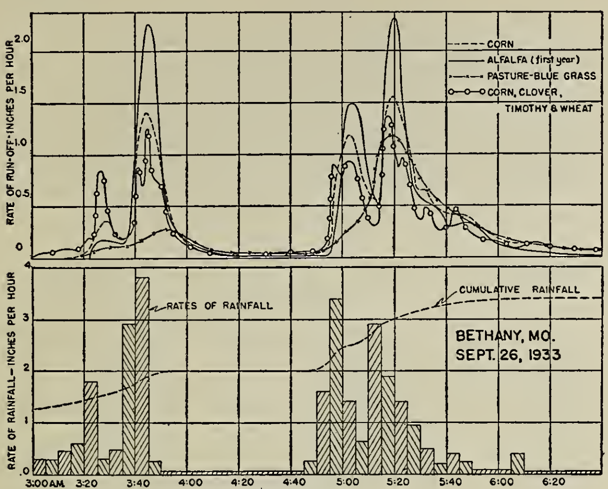


FIGURE 27.

Cover, farm operations, erosion-control practices, etc.—Old established bluegrass sod, age about 40 years. Small gullies on this area, checked by metal overfall flumes. A few large shade trees under which is a complete cover of bluegrass. Moderately grazed. A dense protective cover of grass at the time of this rain.

Area D–3 North

Character.—Corn; 4.85 acres drainage area; 6.7 percent average land slope.

Soil.—Thirty-five percent of area deep phase Shelby soil; 60 percent shallow phasc Shelby; 2 or 3 percent Shelby subsoil and small gullies; 2 percent Grundy silt loam.

Cover, farm operations, erosion-control practices, etc.—A rotation of clover and timothy, corn, corn, and oats is practiced on this area. This area was in clover and timothy in 1932 and in corn, check-rowed, in 1933. The corn suffered about 40-percent damage from chinch bugs during the season so that the stand was considerably thinned out. Corn had about reached full growth at the time of this rain.

Area I–J1

Character.—Strip-cropped; 2.13 acres drainage area; 9.2 percent average land slope.

Soil.—Fifty percent of area is Shelby deep phase soil; 45 percent Shelby shallow phase; about 2 percent Shelby subsoil exposed; and about 3 percent colluvial material.

Cover, farm operations, erosion-control practices, etc.—This field is cropped in four strips with crop boundaries located approximately on the contour. The crops which are rotated on the four strips are corn, soybeans, wheat, and clover and timothy. Oats attained a heavy growth on this area which, after harvest, was followed by a heavy growth of young clover, timothy, weeds, and wild grass, thus maintaining almost a perfect cover. Corn suffered severe damage from chinch bugs, requiring replanting in the latter part of June. Soybeans were slow in getting started but maintained excellent growth throughout the summer. The soybean area was disced prior to the seeding of wheat on September 25.

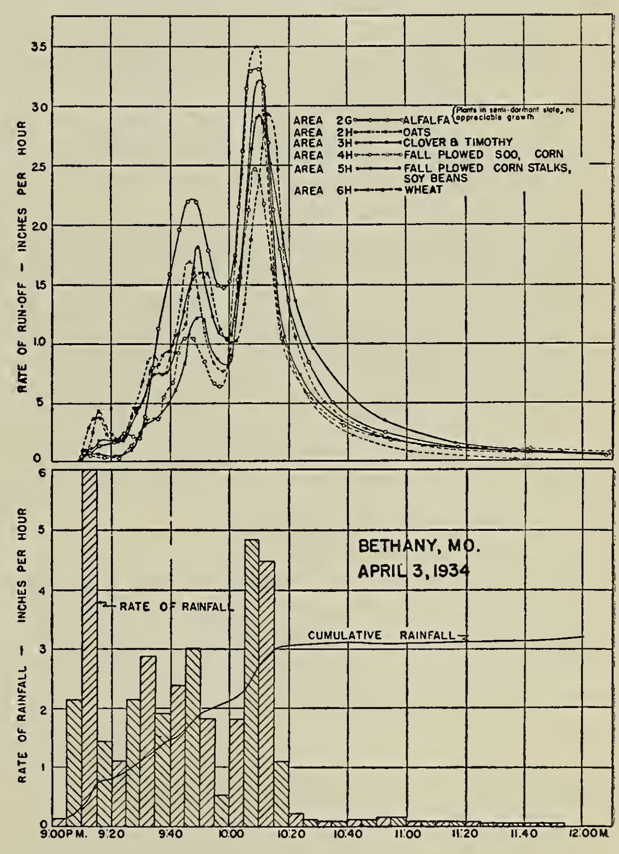
Area I–58

Character.—Alfalfa, first year; 2.11 acres drainage area; 9.1 percent average land slope.

Soil.—Practically same as for IJ–1.

Cover, farm operations, erosion-control practices, etc.—The winter wheat cover crop was plowed under in the spring of 1933 and barley and alfalfa were seeded, the barley serving as a nurse crop to aid in the establishing of the alfalfa. A good stand of alfalfa just getting established afforded rather poor protection to soil.

HYDROGRAPH OF APRIL 3, 1934, AT BETHANY, MO.—FIGURE 28A



Terrace 2–G

Character.—Alfalfa, plants in semidormant state, no appreciable growth; 0.75 acre drainage area; 12 percent average land slope.

Soil.—Shelby sandy loam soil; about 65 percent of area shallow phase, 1 to 4 inches deep; 25 to 30 percent deep phase, 4 to 7 inches deep; 5 to 10 percent of subsoil exposed, consisting of tight, plastic clay with considerable sand and a little gravel. A large gully, 20 to 30 feet wide, 5 to 6 feet deep, extending full length of slope, was filled before terraces were constructed.

Cover, farm operations, erosion-control practices, etc.—Second year alfalfa on this area. Alfalfa had not attained much growth at the time of this rain, and did not afford much protection to the soil. Length of terrace 650 feet, vertical interval 5 feet, uniform grade of 4 inches per 100 feet.

Terrace 2–H

Character.—Oats; 1.46 acres drainage area; 8.3 percent average land slope.

Soil.—Practically the same as for 2–G.

Cover, farm operations, erosion-control practices, etc.—This area was planted to oats but practically no protection was afforded to the ground surface at the time of this rain. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

Terrace 3–H

Character.—Clover and timothy; 1.41 acres drainage; 8.5 percent average land slope.

Soil.—Practically the same as for 2–G.

Cover, farm operations, erosion-control practices, etc.—This area was in clover and timothy sod which had not attained much growth at the time of this rain when the plants were in a semidormant state. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

Terrace 4–H

Character.—Fall plowed for corn; 1.25 acres drainage area; 9.6 percent average land slope.

Soil.—Practically the same as for 2–G.

Cover, farm operations, erosion-control practices, etc.—This area had been plowed but corn had not been planted at the time of this rain. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

Terrace 5–H

Character.—Fall plowed for soybeans; 1.24 acres drainage area; 9.7 percent average land slope.

Soil.—Practically the same as for 2–G.

Cover, farm operations, erosion-control practices, etc.—Soybeans had not been planted and this land was in fallow at the time of this rain. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

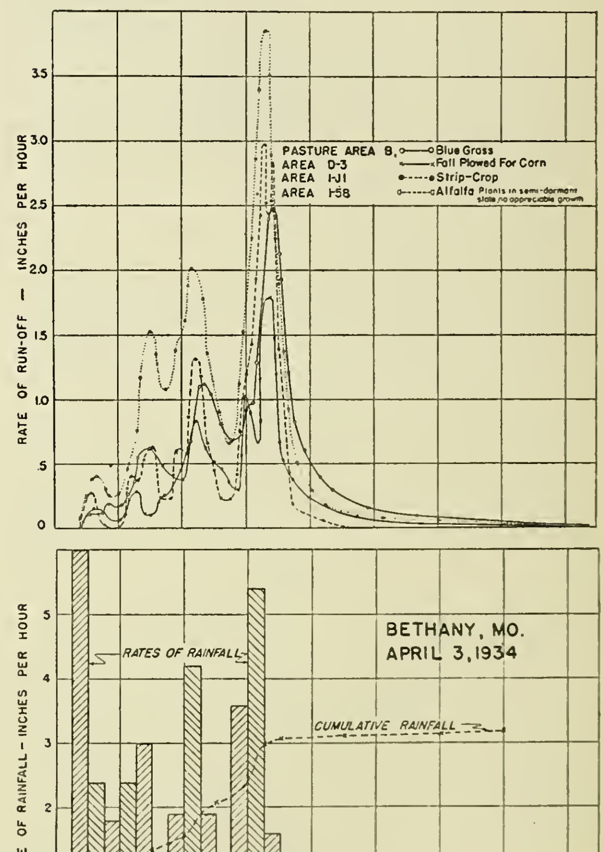
Terrace 6–H

Character.—Wheat; 1.23 acres drainage area; 9.8 percent average land slope.

Soil.—Practically the same as for 2–G.

Cover, farm operations, erosion-control practices, etc.—Wheat had not attained much growth at the time of this rain and did not afford much protection to the soil. Length of terrace 1,050 feet, vertical interval 5 feet, variable grade of level to 4 inches per 100 feet.

HYDROGRAPH OF APRIL 3, 1934, AT BETHANY, MO.—FIGURE 28B



Area B

Character.—Bluegrass pasture; 6.52 acres drainage area; 9.5 percent average land slope.

Soil.—Seventy percent of area Shelby sandy loam deep phase, 4 to 7 inches deep; 15 percent shallow phase, 1 to 4 inches deep; 5 percent colluvial material, 10 percent Grundy silt loam, 8 to 18 inches deep, underlayed by

pliable, porous clay loam; one-fourth of 1 percent of area is gullied.

Cover, farm operations, erosion-control practices, etc.—Old established bluegrass sod, age about 40 years. Small gullies on this area checked by metal overfall flumes. A few large shade trees under which is a complete cover of bluegrass. Moderately grazed. A dense protective cover of grass at the time of this rain. A good bluegrass sod, but grass had not attained much growth at the time of this rain.

Area D–3 North

Character.—Fall plowed for corn; 4.85 acres drainage area; 6.7 percent average land slope.

Soil.—Thirty-five percent of area deep phase Shelby soil; 60 percent shallow phase Shelby; 2 or 3 percent Shelby subsoil and small gullies; 2 percent Grundy silt loam.

Cover, farm operations, erosion-control practices, etc.—A rotation of clover and timothy, corn, corn, and oats is practiced on this area. This area was in corn in 1933 and in corn again in 1934. On April 3, the time of this rain, the corn had not yet been planted but the field had been plowed.

Area I–J1

Character.—Strip-cropped; 2.13 acres drainage area; 9.2 percent average land slope.

Soil.—Fifty percent of area is Shelby deep phase soil; 45 percent Shelby shallow phase; about 2 percent Shelby subsoil exposed; and about 3 percent colluvial material.

Cover, farm operations, erosion-control practices, etc.—This field is cropped in four strips with crop boundaries located approximately on the contour. The crops which are rotated on the four strips are corn, soybeans, wheat, and clover and timothy. The crops on the four strips during 1934 from top to bottom of slope: Clover, corn, soybeans followed by wheat, and wheat followed by clover and timothy. Ground had been plowed but corn and soybeans had not been planted at the time of this rain.

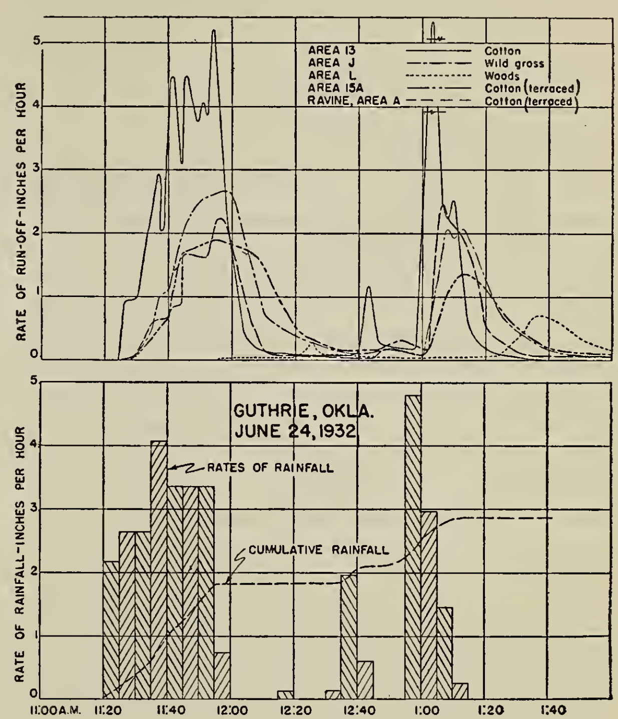
Area I–58

Character.—Alfalfa in semidormant state; 2.11 acres drainage area; 9.1 percent average land slope.

Soil.—Soil is practically the same as for I–J1.

Cover, farm operations, erosion-control practices, etc.—The winter wheat cover crop was plowed under in the spring of 1933 and barley and alfalfa were seeded, the barley serving as a nurse crop to aid in the establishing of the alfalfa. At the time of this rain the alfalfa was in a semidormant state and did not afford much protection to the soil.

Hydrograph of June 24, 1932, at Guthrie, Olka.—Figure 29



Area 13

Character.—Cotton; 3.6 acres drainage area; 5.13 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Wheat cover crop during winter months of 1931–32. Plowed with moleboard plow during first week of April 1932. Cotton was planted in contour rows on May 15, 1932. Was cultivated on June 15 and July 20.

Area 15–A

Character.—Cotton terraced; 3.13 acres drainage area; 3.42 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded and badly gullied prior to terracing.

Cover, farm operations, erosion-control practices, etc.—Four level terraces on this area. Crops and farm operations same as for Area 13.

Area J

Character.—Wild grasses; 5.28 acres drainage area; 4.44 percent average land slope.

Soil.—Vernon fine sandy loam soil.

Cover, farm operations, erosion control practices, etc.—Abandoned gullied grass land area formerly cultivated but

now covered with a growth of native grasses and weeds. This area was not pastured and vegetation had attained a matured height at the time of this rain.

Area L

Character.—Woods; 5.62 acres drainage area; 4.8 percent average land slope.

Soils.—A typical Vernon sandy loam soil, noneroded phase, with a rich mantle of black humus resulting from the decay of oak leaves and dead grass. Heavy, impervious red clay at depth of 3 or 4 feet.

Cover, farm operations, erosion-control practices, etc.—Cover is 90 percent scrub oak with a scattering of white oak, persimmon, and cottonwood. A few small open areas, covered with grass and oak sprouts, constitute less than 10 percent of the total watershed. Due to highly absorptive topsoil, run-off was very small for ordinary rains and not until this soil became saturated did any appreciable run-off occur. At the time of this rain trees were in full foliage and grass had attained a matured height.

Ravine A Area

Character.—Cotton, terraced; 35 acres drainage area; 4.94 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Long terraces with small grade. Crops and farm operations same as for Area 13.

Hydrograph of October 3, 1932, at Guthrie, Okla.—Figure 30

Area 13

Character.—Cotton; 3.6 acres drainage area; 5.13 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Wheat cover crop during winter months of 1931–32. Plowed with moleboard plow during first week of April 1932.

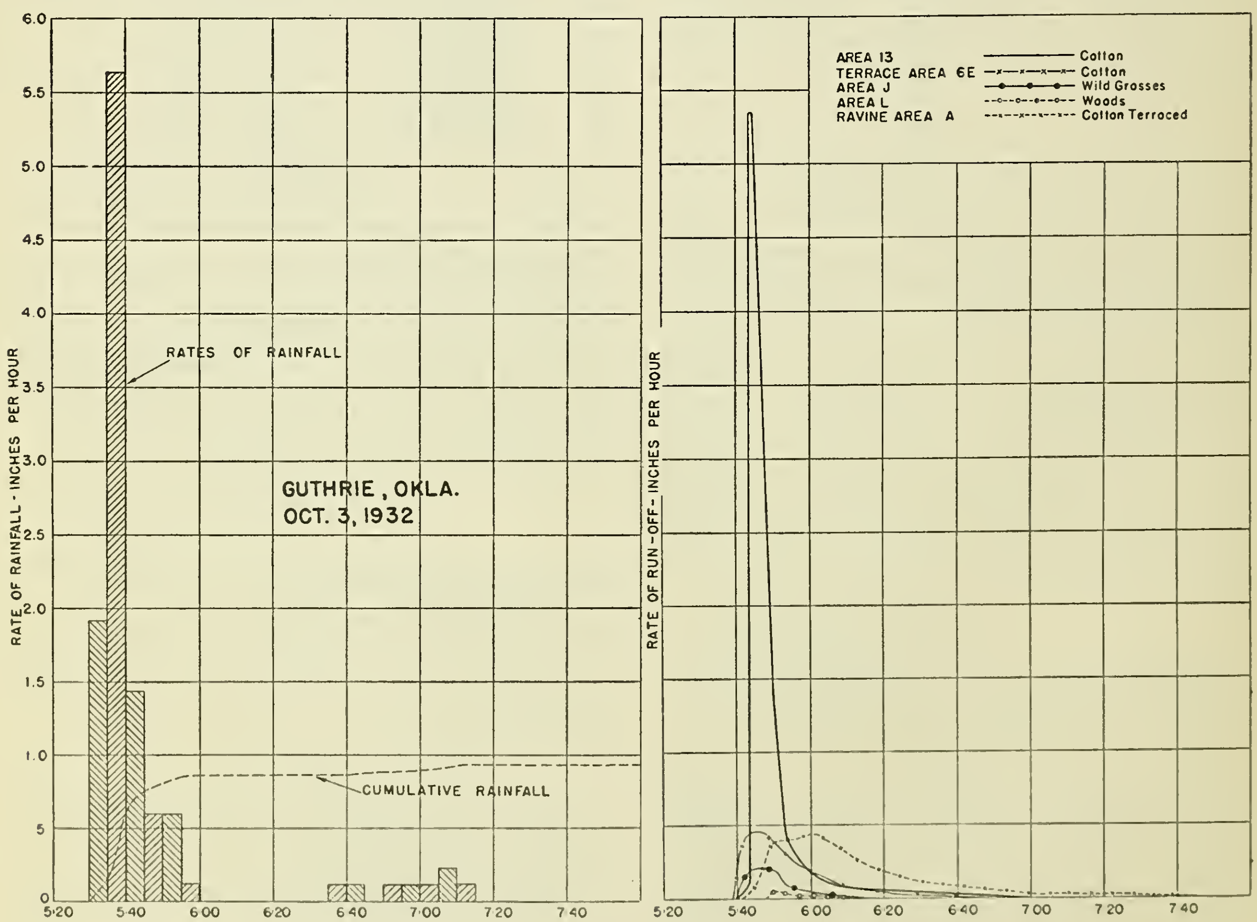


Figure 30.

Cotton was planted in contour rows on May 15, 1932. Was cultivated on June 15 and July 20. Picking of cotton was completed on October 14, 1932. A cover crop of winter wheat was planted on October 17, 1932.

Area 15–A

Character.—Cotton, terraced; 3.13 acres drainage area; 3.42 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded and badly gullied prior to terracing.

Cover, farm operations, erosion-control practices, etc.—Four level terraces on this area. Crops and farm operations same as for Area 13.

Terrace 6–E

Character.—Cotton; 1.2 acres drainage area; 4.56 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—One level terrace 650 feet long. Crops and farm operations same as for Area 13.

Area J

Character.—Wild grasses; 5.28 acres drainage area; 4.44 percent average land slope.

Soil.—Vernon fine sandy loam soil.

Cover, farm operations, erosion-control practices, etc.—Abandoned gullied grass-land area formerly cultivated but now covered with a growth of native grasses and weeds. This area was not pastured and vegetation had attained a matured height at the time of this rain.

Area L

Character.—Woods; 5.62 acres drainage area; 4.8 percent average land slope.

Soil.—A typical Vernon sandy loam soil, noneroded phase, with a rich mantle of black humus resulting from the decay of oak leaves and dead grass. Heavy, impervious clay at depth of 3 or 4 feet.

Cover, farm operation, erosion-control practices, etc.—Cover is 90 percent scrub oak with a scattering of white oak, persimmon, and cottonwood. A few small open areas, covered with grass and oak sprouts, constitute less than 10 percent of the total watershed. Due to highly absorptive topsoil, run-off was very small for ordinary rains and not until this soil became saturated did any appreciable run-off occur. At the time of this rain trees were in full foliage and grass had attained a matured height.

Ravine A Area

Character.—Cotton, terraced; 35 acres drainage area; 4.94 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Long terraces with small grade. Crops and farm operations same as for Area 13.

HYDROGRAPH OF MAY 3, 1934, AT GUTHRIE, OKLA.—FIGURE 31

Area 13

Character.—Cotton; 3.21 acres drainage area; 5.13 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Cultivated in cotton with rows running across the slope; not terraced. This area was plowed with a moleboard plow on October 10, 1933, and was left in a fallow condition until the last week in April 1934, when it was tandem disced and planted to cotton just prior to the rain of May 3.

Area 15–A

Character.—Cotton, terraced; 3.13 acres drainage area; 3.42 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded and badly gullied prior to terracing.

Cover, farm operations, erosion-control practices, etc.—Planted to cotton with rows parallel to terraces. Farm operations for this area same as for Area 13 given above. Four level terraces on this area.

Terrace 6–E

Character.—Cotton; 1.2 acres drainage area; 4.56 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—One level terrace 650 feet long. Cultivated to cotton with rows parallel to terrace. Farm operations same as for Area 13.

Area J

Character.—Wild grasses; 5.28 acres drainage area; 4.44 percent average land slope.

Soil.—Vernon fine sandy loam soil.

Cover, farm operations, erosion-control practices, etc.—Abandoned gullied grass land area formerly cultivated but now covered with a growth of native grasses and weeds. Grass had attained a fairly good growth at the time of this rain. Not pastured.

Area L

Character.—Woods; 5.62 acres drainage area; 4.8 percent average land slope.

Soil.—A typical Vernon sandy loam soil, noneroded phase, with a rich mantle of black humus resulting from the decay of oak leaves and dead grass. Heavy impervious red clay at depth of 3 or 4 feet.

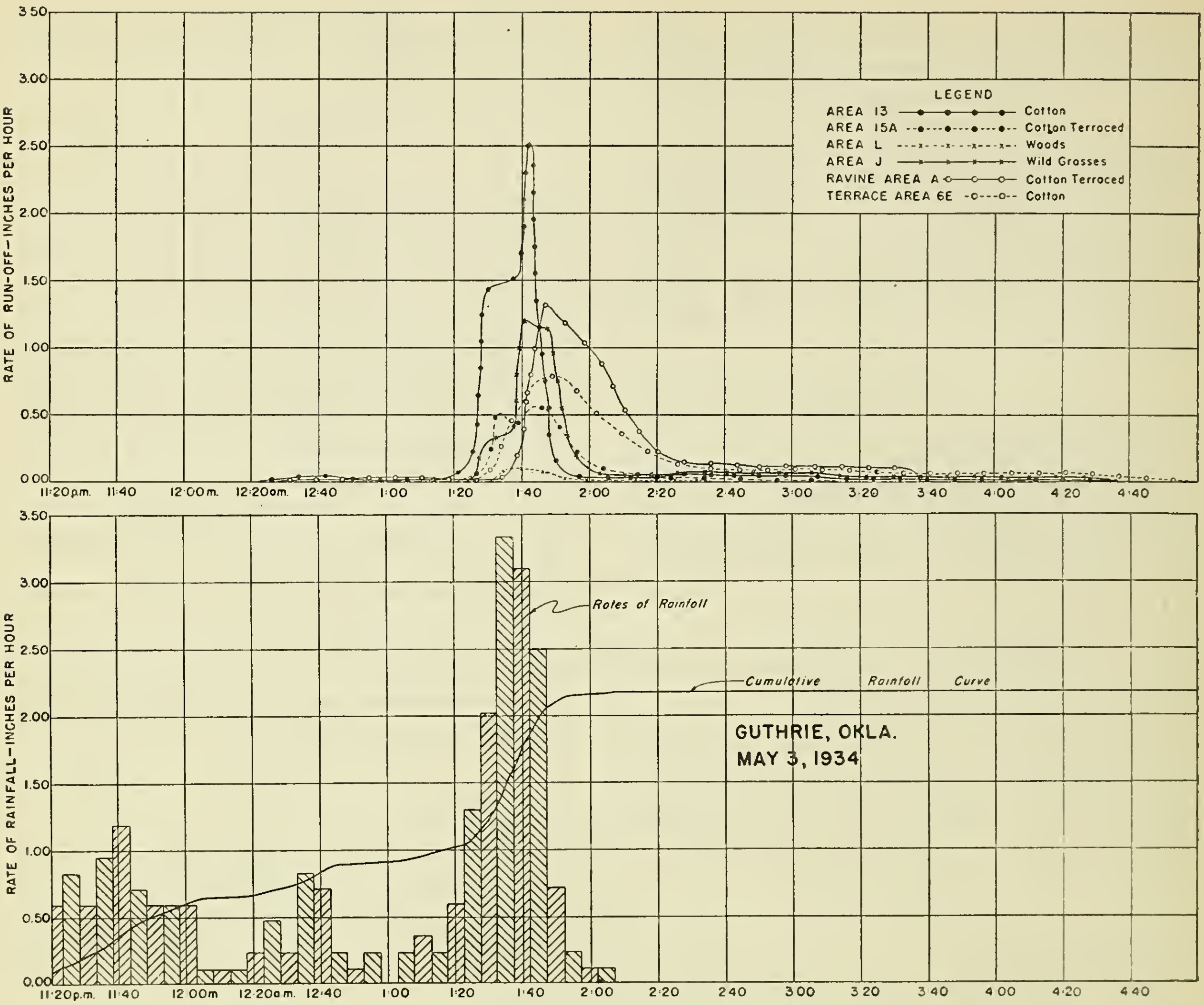


Figure 31.

Cover, farm operations, erosion-control practices, etc.—Cover is 90 percent scrub oak with a scattering of white oak, persimmon, and cottonwood. A few small open areas, covered with grass and oak sprouts, constitute less than 10 percent of the total watershed. Due to highly absorptive topsoil, run-off was very small for ordinary rains and not until this soil became saturated did any appreciable run-off occur. Growth of grass on this area had not reached maturity at the time of this rain. Trees in fairly full foliage.

Ravine A Area

Character.—Cotton, terraced; 35 acres drainage area; 4.94 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Cultivated to cotton with rows paralleling terraces. Long terraces with small grade. Farm operations same as for Area 13.

Hydrograph of September 9 and 10, 1934, at Guthrie, Okla.—Figure 32

Area 13

Character.—Cotton; 3.21 acres drainage area; 5.13 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Cultivated in cotton with rows running across the slope. Not terraced. This area was plowed with a moleboard plow on October 10, 1933, and was left in a fallow condition until the last week in April 1934 when it was

tandem disced and planted to cotton. The cotton was cultivated on May 22 and June 30, 1934.

Area 15–A

Character.—Cotton, terraced; 3.13 acres drainage area; 3.42 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, and badly gullied prior to terracing.

Cover, farm operations, erosion-control practices, etc.—Four level terraces on this area. Planted to cotton with rows parallel to terraces. Farm operations for this area same as for Area 13.

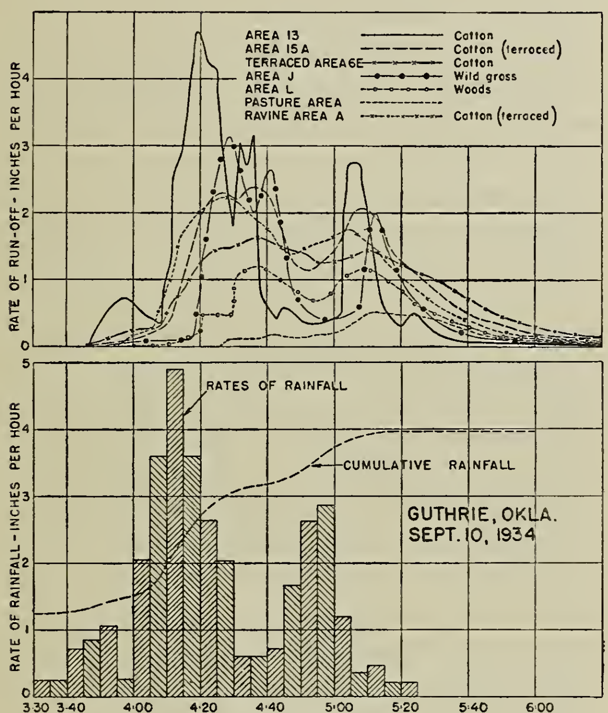


FIGURE 32.

Terrace 6–E

Character.—Cotton; 1.2 acres drainage area; 4.56 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—One level terrace 650 feet long. Cultivated to cotton with rows parallel to terrace. Farm operations same as for Area 13.

Area J

Character.—Wild grasses; 5.28 acres drainage area; 4.44 percent average land slope.

Soil.—Vernon fine sandy loam soil.

Cover, farm operations, erosion-control practices, etc.—Abandoned gullied grass-land area formerly cultivated but now covered with a growth of native grasses and weeds. This area was not pastured and vegetation had attained a matured height at the time of this rain.

Area L

Character.—Woods; 5.62 acres drainage area; 4.8 percent average land slope.

Soil.—A typical Vernon sandy loam soil, noneroded phase, with a rich mantle of black humus resulting from the decay of oak leaves and dead grass. Heavy, impervious red clay at depth of 3 or 4 feet.

Cover, farm operations, erosion-control practices, etc.—Cover is 90 percent scrub oak with scattering of white oak, persimmon, and cottonwood. A few small open areas covered with grass and oak sprouts constitute less than 10 percent of the total watershed. Due to highly absorptive topsoil, run-off was very small for ordinary rains and not until this soil became saturated did any appreciable run-off occur. At the time of this rain trees were in full foliage and grass had attained a matured height.

Pasture Area

Character.—2.5 acres drainage area; 5.65 percent average land slope.

Soil.—Soil similar to that in area L.

Cover, farm operations, erosion-control practices, etc.—Cover of native grass and small shrubs with no gullies or bare spots. Heavy growth of typical Oklahoma grasses consisting principally of poverty grass, little and big bluestem with some wild lespedeza and gramma grass. Topsoil highly absorptive, similar to that in the wooded area mentioned above. Practically no erosion. While this area is designated as pasture, no grazing occurred on this area during 1934.

Ravine A Area

Character.—Cotton, terraced; 35 acres drainage area; 4.94 percent average land slope.

Soil.—Vernon fine sandy loam soil, severely eroded, subsoil exposed, which is quite impervious.

Cover, farm operations, erosion-control practices, etc.—Cultivated to cotton with rows paralleling terraces. Long terraces with small grade. Farm operations same as for Area 13.

CHAPTER IV

INFLUENCE OF VEGETATION ON LAND-WATER RELATIONSHIPS

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POINTS OF VIEW

IF WE LIVED in the desert and our lives depended upon a water supply that came out of a steel tube, we would inevitably watch that tube and talk about it understandingly. No citizen would need to be lectured about this duty toward its care or spurred to help if it were in danger. Teachers of civics in such a community might develop a sense of public responsibility, not only by describing the remote beginnings of the commonwealth, but also how that tube got built, how long it would last, how vital the intake might be if the rainfall on the forested mountains nearby ever changed in seasonal habit or amount. It would be a most unimaginative person, or a stupid one, who could not see the vital relation between the mountains, the forests, that tube, and himself.

Unfortunately it takes much more imagination and an unaccustomed degree of civic responsibility to sense the true state of affairs in those parts of the country where there is no actual desert and where water for all purposes does not come out of a steel tube but from springs, that seem to the laymen to be fed mysteriously within the earth, and from streams whose sources are so far distant as to appear to be quite outside the realm of individual responsibility. We hear it said that a wholesome national life depends upon good racial stock of high character, a flourishing state of industry and trade, and a workable form of government. All these things are vital, but in a fundamental sense our life depends in the first instance on moisture and heat. Without these in favorable amounts and seasons the plant and animal capacities of the earth are unrealizable.

There is a further difficulty in trying to sense our dependence upon water: Control and delivery are technical matters based on scientific study. The object of water management is not to determine the maximum amount that can be delivered at a given point in a given period of time but rather the amount that should be delivered in a given period to produce maximum efficiency; that is, no unnecessary waste in use, no damage to other resources on the way to the places of use, and continued or long-range use determined by priorities of need. This means that water management requires attention to many factors in a complicated relationship that is determinable only through research; that is, experiment, measurement, calculation, comparison—with respect to rainfall, snowfall, stream flow, sedimentation, trees, grasses, slopes, rocks, timber-cutting, irrigation, pasturing, and agricultural practices generally. Not every citizen, therefore, can understand why management should proceed in a given way. Happily, the principles or broad generalizations can be understood by the citizen; and the obligation of scientists to state their findings in simple terms (when possible) is now widely recognized.

If not strictly twins, soil and vegetation are at least brothers in the same family. Interactive throughout their life histories, if one of them disappears, the other (with some exceptions) survives upon a lower plane. Those dwarfs, the "short grasses", serve to illustrate this interaction. They owe their low stature to a sharply

limited water supply characteristic of their range. Their survival is based upon the efficiency of their root systems in the interception and use of a high maximum of available water. The individual plants wage keen competition underground by the occupation of the whole surface layer of soil with a fine net of rootlets. By far the larger part of an individual among dry-land grasses is underground, and the role of the stem is to employ chemical and solar energies and make their effects available in the economy of the plant. Once established, this root-net binds the soil against excessive surface erosion, gives a high absorptive power to the soil by providing a multitude of root channels and by helping to promote a crumb structure, and, like the rest of the plant, it enriches the soil through the chemical break-down of its debris. Under these conditions soil and plant are the right and left hands of the argument.

Perhaps nowhere in the world is the interaction between soil and plant so nicely maintained as in the short-grass areas of plains vegetation, where the depth of the carbonate layer delimits [1] the level to which the absorption of water and nutrients usually takes place. It is in the surface zone of the marvelously efficient root systems of short grasses that all of the available moisture is appropriated each year, and there is virtually no penetration of surface water to deeper levels. The gross amount of average annual precipitation or its seasonal distribution are but poor indicators of the amount of water available to given plants in a given soil of the short-grass region.

It was the chief contribution of soil science in earlier years to show that the interaction of soil and vegetation, under the conditions of a given climate, as well as the mineral ingredients of the underlying rock, are responsible for those ultimate qualities of mature soils that give them their specific physical character and fertility from region to region. Thornthwaite [2] finds that mature soils and climax vegetation follow climatic lines in Oklahoma, while immature soils and subclimax vegetation reflect the underlying rock types. In general, the deeper we go the more like the parent rock the soil becomes. We have to conclude that both the vegetation and the soil profiles from region to region are determined largely by the parent soil material and the climate.

Scientific agriculture attempts to maintain the natural harmony between vegetation and soil, or improve upon it. Scientific forestry and grazing, two specialized aspects of agriculture, seek to do the same thing. If that harmony is preserved by science, plus public control, where necessary, all other things will be added unto it—flood crests will be lower, silting of reservoirs will be diminished, and water can be distributed over fields for irrigation or delivered to city mains, mill wheels, and power stations more efficiently. "For the tree of the field is man's life" was written by a man who saw several thousand years ago how nature was organized in a semiarid upland (not unlike parts of Idaho and Nevada).

When causes and effects are in different places and the resources to which they are tied are controlled by different individuals and agencies, the difficulty of seeing fundamental relationships is sometimes increased by not wanting to see them. "Nothing interferes with progress so much as not wanting to make it." A mountain forest of interest to the lumberman may be hundreds of miles from the irrigated fields or mills where the run-off from the forested area is used for further economic purposes. It is not always and at once apparent that there is a community of interest. Only when the land is filled up and human rela-

[1] This is from 10 to 18 inches. Weaver and Harmon found, near Lincoln, Nebr., that more than half of the underground living parts of grasses is in the top 6 inches of soil and constitutes about one-tenth by weight of the total organic matter in this 6-inch layer (Weaver, J. E., and Harmon, G. W., *Quantity of Living Plant Materials in Prairie Soils in Relation to Run-off and Soil Erosion.* Nebraska University, Conservation Department, Bulletin 8, 53 pp., illus. 1935. See p. 46).

[2] Thornthwaite, C. W., *Letter of Aug. 8, 1936, to Dr. Isaiah Bowman*, 13 pp. (See p. 2.)

tions become complex do we see new unities emerge that tie together conditions and welfares that have long been independently maintained.

The world's densest populations are found on either flat or moderately rolling land. Probably three-fourths of our 2 billion earth-bound inhabitants live on plains and low uplands whose main drainages are visited by floods, the sources and causes of which are often, if not generally, in another physiographic environment. Concentrated effort at dams and along riverbanks is required once a flood has arrived. Such narrow emergency treatment on the bank of a stream is a quite different thing from the broad treatment of land and vegetation at the sources of streams. Out of that breadth of treatment comes one of the difficulties of the problem of water control. There is no dramatic concentration of power and effect, as at Boulder Dam, for example. Spread out over vast areas is almost an infinity of cause and effect. It is the sum of all the grass stems, individual trees and shrubs, trickles of water, ravines, snowbanks, summer storms, and grazing and timber-cutting effects that we see in a given case, whether of soil erosion or preservation, or water conservation, or needless waste.

There have always been floods, and they have helped build some of the best lands in the world. Our lowlands were largely built by floodwaters. When men occupied the lowlands their fields were in competition with the floods; and on the largest temperate-zone lowlands the competition grew keener with the expansion and growing density of population. But control of lowland floods by upper watershed management was not then feasible. It is only in the last hundred years that general correlation of control efforts could be realized in watersheds considered as units. How far competition with and control of nature has gone in one direction is indicated by Eakin.[3] He finds that aggradation of the Yazoo Basin has filled the original channels and valley in many places up to datum levels of maximum primeval floods.

From the standpoint of control, varied and sometimes conflicting uses mean, first, science; then, management plans based on science; and, finally, cooperation in the application of standardized practice. These objectives are beyond the power of the individual to achieve singlehandedly, though requiring his cooperation. While cooperation is the first law of agriculture in the desert, where irrigation ditches and dams are required beyond individual power to create, and where access to water is vital to all, it is harder to make it the first law of watershed protection where communities of different types occupy different parts of the same watershed. Relatively easy to see in the arid West, it is in many places difficult to see in the humid East. Vegetation is one of the few directly controllable elements in the chain of conditions and relations that affect the headwater areas, the soils, the cultivated land, the livestock ranges, and the natural slopes throughout the country. It is here, therefore, that research and management should strike in to determine the best physical and economic types and conditions of control.

When the droughts and duststorms come we hear of prayers for rain by families or whole communities. It would be far more sensible and rational to pray for intelligence enough to take proper care of the soil and of the vegetable cover when there is no drought. As soon as the drought is over the prayers cease, the Government turns to other business, and the taxpayers go on paying the cost of the drought from which there is no relief by prayer or otherwise. The rains will fail or fall, no matter what party is in power. No political leader can fight the sky and Providence. What can be done will reduce the humps and raise the hollows of soil and groundwater changes—steady, long-range work which is apt to be neglected as soon as we think that the evil genii of nature are on a holiday. That is bad business, for the conservation of land and

[3] Eakin, H. M., The Twin Problems of Erosion and Flood-Control, *American Geophysical Union, Trans.* 17th Annual Meeting, pt. 2, pp. 436–439. 1936.

water means also the conservation of people, which always brings profits in the end. Water waste and its attendant evils have already done more material damage to the United States than war. The reduction of the amount of damage will not be clear gain; it will always cost money to improve either nature or human nature.

Man was given "dominion over the works of thy hands"; and the bases of that dominion are reason and foresight. By using them we can destroy weeds, destructive insects, and predatory animals; level inequalities here and there in the land surface; and impound waters. But in the mass people are not taught through reason and foresight. Calamity is the great teacher. Only when the sky is filled with ominous dust and people are starving does America think nationally about the problem of the arid West and of the human values that are a part of the problem. By neglecting the problem we also destroy good land. Of the vast area of over 100 million acres that includes extreme forms of erosion in the West, over a third is comprised of abandoned wheat farms, and upon the portion that was originally sodded it will take from 15 to 50 years to restore a suitable cover and to redeem the local deserts that cultivation imposed. We shall never have enough of the best land. Only 75 million out of 350 million acres of crop land in the United States are level. Our leading crops are grown largely upon sloping land, where cultivation brings accelerated erosion hazard and higher flood crests.

We have been too long in the wild Indian stage, willing to scalp the land and leave it a red horror. If culture is primarily "an inner attitude of mind", we have only begun to be civilized with respect to our soil inheritance, for at last we have begun to show a real national conviction and concern for it. It is said that man is "marvelously undulating and perverse", and perhaps no part of his career more persuasively illustrates this truth than his treatment of soil fertility—pouring hundreds of millions of dollars worth of fertilizer into the soil in one region and encouraging and even forcing the flight and irrevocable loss of other hundreds of millions and even billions of dollars' worth of soil fertility elsewhere which might be saved through the application of reason and foresight.

EROSION AND VEGETATION POTENTIALS

Plant, litter, soil humus, plant—these constitute a vegetational cycle made dynamic through moisture, heat, and the mineral ingredients of the soil, plus a plant mechanism that also utilizes sunlight and air. All these interacting elements and processes aid in the production of the soil of a given place. What man does to the plant cover, what happens to the soil when the surface layer is destroyed, how the soil should be treated to avoid destruction—these are among the questions that enter vitally into the discussions of the present conference.

The interactions of the soil-building and soil-conserving forces are so variable from region to region that the first duty of soil science toward an upstream engineering program is to determine the ecological status and functions of the plant cover and the composition and dynamics of the soil from place to place. Erosion effects cannot be measured directly by type of vegetational change. Weeds may be as effective as grass in retarding erosion, and brush and scrub nearly as effective as forest. Management must vary according to local or regional conditions; it can neither start nor stop with a few sweeping generalities. Future research, to an even greater degree than present research, should concern itself with the experimental determination and identification of plant and soil characteristics and distinctions from region to region, depending upon locally unique combinations of four primary elements: Plant cover, land type, necessary mineral ingredients, and climatic conditions. A stable plant cover and a given declivity of slope may be the critical combination in one place; ground moisture and soil in another.

Anyone can see that the situation is critical

when the soil is actually eroding. But science has an even more important job: to forecast erosion in places where it has not yet begun. This is done in part by determining the "erosion potential" of each area; that is, the degree of susceptibility to erosion under prevailing conditions. It is the topsoil especially that we want to preserve, and that is a thin layer built up over a period of time, varying from a few years to many years, easily lost under common types of cultivation on slopes above 10 percent, and at least in some places unrecoverable once it is lost. That is what the early seventeenth-century observer meant who wrote "I think that whosoever doth not maintain the plough, destroys this kingdom."

Erosion potential is a measurable thing. There are techniques of observation and calculation that permit one to say that a given area is in no danger of losing its topsoil, or that it is in grave danger if a given element of "the balance of nature" is altered. Such conclusions, to be most valuable, are required long before the landscape is visibly scarred. In fact, the topsoil may be lost by slow wasting from the whole surface without any gullying at all. To observe and measure what is happening to the soil and, under given conditions, to forecast the end result is what we need in any scientific and long-range program. Such a forecast will give increasing attention, as knowledge grows, to what are called the B and C soil horizons below the surface or A horizon. Erosional products are not made up of topsoil only. Both flood control and productivity require the maintenance or restoration of the A horizon if that can be done. If the surface layer is lost, we do not always get the same kind of soil below it with only humus lacking. The B and C horizons may be much more or much less porous than the surface layer, and either of these conditions may be undesirable and even fatal. What happens in each case and at each successive level depends also upon the rainfall habit of the region, the type of vegetation or cultivation, the presence or absence of winter frost, and so on. Restoration measures will be required to vary accordingly.

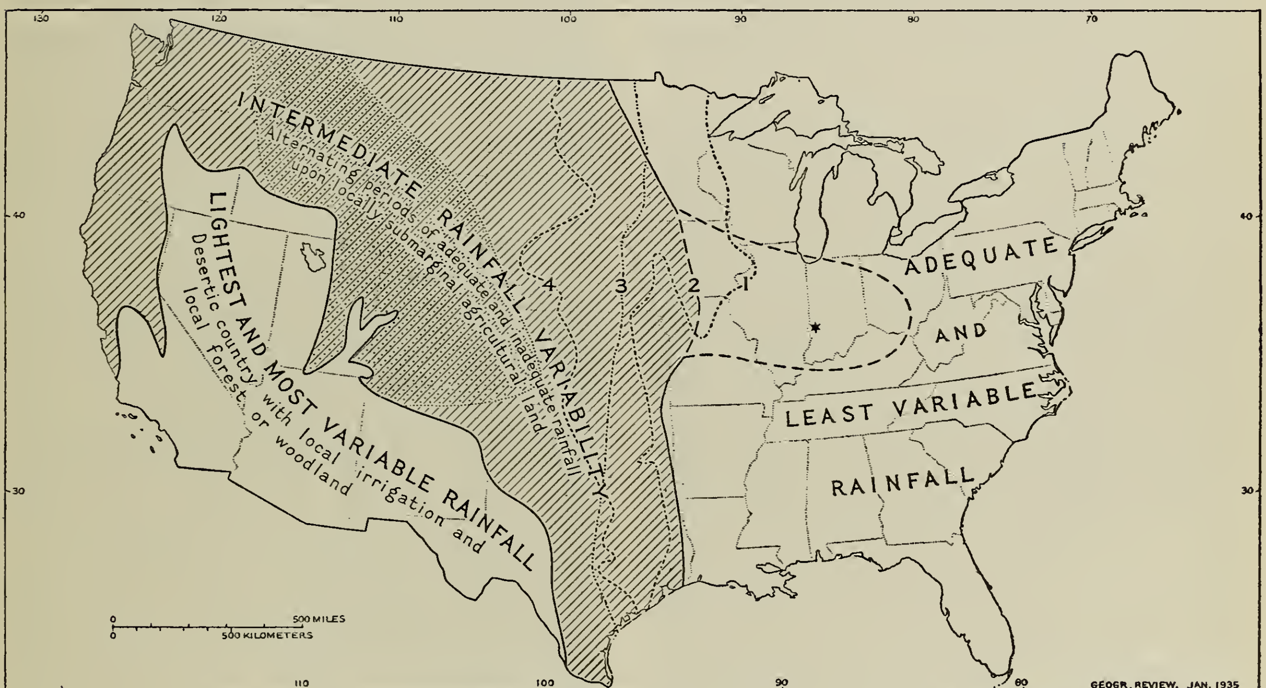
There is a vegetation potential just as there is an erosion potential. There is also a vegetational balance analogous to the balance between soil horizons when a state of soil maturity has been reached. One can destroy the vegetation of certain areas and completely change the floristic balance for generations. This may be done by destroying the surface soil and exposing the B or C horizons, or by changing the level of the water table or the quantity or duration of soil moisture, or by giving weeds a handicap over useful plants. The possibility of destruction, or of evil change, varies enormously from region to region, and tendencies and effects must be measured and determined, not merely guessed at.

THE INTERPRETATION OF RAINFALL VARIABILITY

To take a single variant among those that affect vegetational variability: The map of the United States (fig. 33) shows three broad belts of territory, an eastern belt of least variability in rainfall (measuring changes in percentage of the total), a southwestern belt of extreme variability, and an intermediate belt of less extreme variability. Below these broad areas in rank are the smaller regions and still smaller subregions, each one having its own conditions and requiring separate experimental study. Insofar as vegetation constitutes one of the critical elements of erosion in a given area, the detailed rainfall distribution of that area (amount, seasonal distribution, variability, and rise or fall with respect to critical levels for a given type of vegetation) is a matter of primary importance in determining watershed management.

Research upon the meaning of rainfall variability expressed in terms of plant growth is far behind the requirements of urgent practical problems of vegetational control. Some measure of variability must be found to bring out the fact that each type of agricultural land use and

each type of vegetation has critical amounts and periods of effective water supply. This is another way of saying that mere arithmetical expressions of variability are of little value. Yuma, Ariz.,[4] for example, had rainfall in its wettest year of record that was 183 percent above "normal", and in its driest year 88 percent below normal. These tremendous variations represent, however, but 11.41 inches in the wettest year and 0.47 of an inch in the driest year, a difference of only 11 inches. Even in its fall are spread across the critical limiting values for vegetation, and mean much more than variations far above or far below those limits. Thus, Quinault, Wash., has had rainfall variations between 169.22 and 79.21 inches, and regardless of these wide swings it always has sufficient rainfall even in the driest years to remain in the "rain forest" class. Its variations have little meaning for the maintenance of its normal vegetative type, just as in the case of Yuma.



American Geographical Society of New York

Figure 33.

wettest year, Yuma had "desert" conditions. The variation between wettest and driest for Staunton, Va., is three times that of Yuma in amount (51.18 and 16.76 inches), but the percentage variation is much less. In 1930, the driest year, Staunton was within a few points of being "semiarid", and in 1901 it was nearly "wet". These wide extremes in amount of rain-

The finest and most critical climatic line that we have to locate for vegetational and land-use studies in the United States is in the Plains portion of the Middle West. Here decisions on the largest scale have to be made concerning land use. Such decisions will leave permanent grass on one side of a critical line and specialized agriculture on the other. The line [5] will follow

[4] Thornthwaite, C. W. See pp. 4 and 5 of the reference cited in footnote 2.

[5] Thornthwaite, C. W. See p. 7 of the reference cited in footnote 2.

a crooked, not a straight, course if we get the real meaning out of our rainfall figures as applied to specific soil and slope subdivisions. But, in general, it will probably run through eastern North Dakota, central Nebraska and Kansas, west-central Oklahoma, and Fort Worth, Tex. In this location it will reflect the greatest effective rainfall variability in the center of the climatic range, where changes throw an area here into one type of use, there into another. It will mark the center of a belt of greatest risk for the individual who is accustomed to a given technique of land use and practices it without foreknowledge of the consequences in any given year.

For the drawing of such a line we have to make further search for a suitable "index of precipitation." It will not do to take mere ratios that depend upon guesses. In the excellent publication entitled "The Western Range" [6] is a map that purports to show drought frequency that really shows nothing of the sort. It is based upon 75 percent of average rainfall, but this diminished amount is critical for plants only over small areas of their range and under special conditions of soil and slope. Likewise, a map published by the National Resources Board,[7] which shows average percent deviation from mean annual precipitation, is practically meaningless. In calculating such percentages one is merely doing elementary arithmetic in the abstract, not deriving values that have concrete meaning with respect to the growing plants of a region or the specific agricultural uses of the land. When we add that there are soil variations that further alter the meaning of rainfall by absorbing and retaining it at variable rates (thus leading to further variations in amount of soil moisture), we can understand why widespread management-plans should not proceed on the assumption that we already have all the scientific results that we need.

A special and highly important phase of precipitation variability is represented by snow. Its variability of distribution and amount may offset in part or, contrariwise, exaggerate the variation in the total gross precipitation measured in inches of water. Throughout the whole range country where snow falls, the amount and distribution of the fall is of primary concern. The ranchmen of central Montana, for example, are more concerned with the snowfall than the rainfall. The site of every snowdrift is a green pasture the following season, and in places is fenced as a reserve to be used during the period of summer dryness, or the grass is allowed to cure in place as a late autumn supply.

In some sections of the West the diffusion of snowfall best distributes the ground moisture for the ensuing short-season perennials or annuals, while in other sections the concentration of snowfall is best both for range purposes and the supply of springs and streams that make it possible to use the range outside the areas supplied by wells. Snow surveys [8] are now a part of the Weather Bureau programs, and traverses as a basis of estimation of rate, time, and amount of water delivery from snow before the spring melting are now widely made east and west by power and water supply companies and by municipalities.

VEGETATIONAL VARIABILITY

It is not generally realized that the volume of grassy vegetation varies more widely than the annual rainfall in semiarid lands. A correlation may be observed, however, between volumetric vegetational changes and precipitation effectiveness, not total precipitation. A dry-season decrease of rainfall on meadowland in the East

[6] U. S. Department of Agriculture, Forest Service. *The Western Range.* 620 pp., illus. 1936. (U. S. Cong. 74th, 2d sess., S. Doc. 199. See fig. 46, p. 140.)

[7] National Resources Board. *A Report on National Planning and Public Works in Relation to National Resources and Including Land Use and Water Resources, with Findings and Recommendations.* 455 pp., illus. 1934. (See map facing p. 294.)

[8] Church, J. F., Snow Surveying: Its Principles and Possibilities, *Geographical Review* 23 (4): 529–563. 1933.

still leaves the ground covered with grass, but a comparable decrease of rainfall upon some parts of the western range may leave the ground bare. At best, the western-range country [9] is covered with natural vegetation to but 25 to 50 percent of its extent, and in desert areas the coverage may be less than 10 percent. During the 1933–34 drought, 75 percent of the short-grass plants were killed on overgrazed experimental pastures and 65 percent on moderately grazed areas at Hays, western Kansas. Forest Service experiments show a close relation between rainfall and height growth of grass; Smith's wheatgrass near Miles City, Mont., was 13 inches high in 1933, 1 inch in 1934, and 15 inches in 1935. The variations in volume are even more startling. The ratios of volume of black grama grass on square meter plots in southern New Mexico were as 100 to 1 in the years 1926 and 1928, respectively, with no production in 1934. Mixed perennial grasses in central Utah increased 50 percent above normal in 1925, and were 50 percent below normal in 1934. In central Arizona, during the 1934 drought, there was a decline of 77 percent in grass density even on plots protected from grazing.

In land-water relationships the struggle of plant with plant is always important and sometimes crucial. The hardy short grasses,[10] much less susceptible to damage through overuse than other grass types, occupy territory that has been so broken up by homesteaders and thinned by overgrazing as to be largely replaced by weeds and shrubs of low palatability, such as sand sagebrush, Russian thistle, sunflowers, asters, pigweed, goldenrod, and peppergrass. Cactus, yucca, and broomweed are locally added to the list of invaders that have come to occupy up to 40 percent of the cover (where formerly they occupied from 5 to 15 percent) in western Texas and Kansas and eastern Colorado. Not more than 10 to 15 percent of the forage of these regions can be said to be in reasonably good condition. Farther west, in the intermountain area, the native bunch grasses have been largely replaced by weeds that are inedible or of low forage value, such as cheat grass and Russian thistle, or by poisonous plants, or by plants that are mechanically injurious. Part of the change is from perennial grasses to annual grasses of low palatability, the annuals having risen from 10 percent of the stand to 50 percent, judging by studies on sample areas in Idaho, Oregon, and Washington.

The story is the same throughout the range lands of the "semidesert grass" type, a resource of special importance in winter grazing. Fully two-thirds of the semidesert range has less than half the value it once possessed. Data from study plots in Arizona show that the thinning of the plant cover is responsible for increased run-off from summer rains (46 percent) and a greatly increased rate of soil erosion (500 percent). In the original "sagebrush grass" type, the value lay in the rich stand of perennial grasses and weeds growing beneath a rather sparse cover of sagebrush. Through overgrazing the sagebrush has become greatly extended, and it is estimated that the following percentages of the original stands of perennials now represent the change for the worse that has taken place: Central Nevada, 10; western Utah, 36; northern Nevada, 24. Over a large part of the type sagebrush itself is the only feed left for livestock. It is estimated that 6.5 million acres of sagebrush type have been added to the original area at the expense of useful bunch grass in the Northwest and of short grass in Wyoming.

It is the popular impression that a drought is over and its effects speedily offset when the rains commence; but to restore depleted areas to normal requires much more than a single year of average rainfall. Experimental studies [11]

[9] U. S. Department of Agriculture, Forest Service. See pp. 142–146 of the reference cited in footnote 6.

[10] U. S. Department of Agriculture, Forest Service. See pp. 88 to 94 of the reference cited in footnote 6.

[11] U. S. Department of Agriculture, Forest Service. See p. 147 of the reference cited in footnote 6.

show that it takes from 3 to 5 years of favorable precipitation to restore drought-depleted stands of sod-forming grasses and good-seeding bunch grasses, even under conservative grazing.

If a close relation between diminished rainfall and depleted vegetation is a demonstrated fact, and if the swings in amount of vegetation are even wider than those of rainfall, and if restoration runs far into the wet years, it is a matter of first importance to determine, if possible, the probability of recurrent drought. While we cannot say that a given year will certainly be a drought year, it is possible to say that the probability of drought increases the longer a period of wet years continues. There is no known "general law" of drought occurrence and no way (as yet) of determining the intensity of a drought. Available tree-ring interpretations only give the fact of thinness or thickness of the rings. Such rings show precipitation effectiveness; that is, available or usable moisture under given conditions of temperature, soil, and sunlight. This means that in some areas we shall ultimately find close relations between ring thicknesses and gross rainfall amounts as types of trees, soils, rainfall, and evaporation coefficients are in just the right conjunction.

In view of the uncertainties of rainfall in range lands, it is of the greatest consequence that range vegetation be husbanded in dry years and kept in a healthy condition in wet years lest it be ill prepared to withstand drought when it comes. This is also true of shrubby growths and chaparral, open woodland, and the like, in dry situations, or where a given stand, say of succulent range grasses, developed fully in a former moist phase of the climatic cycle or after slow beginnings that are out of pace with man's needs. Most of the western dry country is moist enough to have some economic value and stable enough to be permanently maintained if there is suitable management. Experiment has shown the possibilities of restoration. Taking forage fluctuations into account,[12] management of the range in the national forests of central Utah has improved the stands of forage 100 to 200 percent on the spring ranges and 400 to 500 percent on the depleted summer ranges.

Experiments and observations now available clearly show that we must improve our national bookkeeping system with respect to vegetation and soils, as well as climate, and check outgo against income. We have hundreds of observers at rainfall stations gathering data for short-range weather predictions, but few investigators of the long-range meanings of these instrumental readings and recorded facts. The rain that affects a holiday or a shipment of perishables may seem important at the moment; but it is the effect upon vegetation and soils in the long run that determines whether people can live on an area, or have perishables to ship, or can afford a holiday. In general, the drier a given region the shorter the cycle of plant growth and the greater the need for the maintenance of cover. Remove the cover and erosion accelerates. Remove it by cutting the forest of a critical watershed, or by overgrazing upland pasture, or by tilling a steep and erodable hillside that ought to remain grassed or forested and no known way of restoration may bring the soil back again within acceptable human limits of time. Von Humboldt put the matter neatly over a hundred years ago: "By felling trees, which are adapted to the slopes and summits of mountains, men in every climate prepare for future ages at once two calamities: want of wood and scarcity of water."

EROSIONAL UNBALANCE

Whatever the degree to which favorable conditions of land use are established, every type of soil and slope has an intake capacity that is below the downfall of the heaviest rains. That capacity of intake is desired that guarantees the permanence of the soil under a given use system and not necessarily a maximum intake. Whatever the priorities of water use—grazing or agriculture or city or industrial consumption—an intake

[12] U. S. Department of Agriculture, Forest Service. See p. 145 of the reference cited in footnote 6.

rate must be determined that underwrites soil protection.

Man is especially destructive where he increases the erosional effects in areas undergoing relatively rapid soil loss under natural conditions. The Badland region of South Dakota is a case in point. One of the largest areas in a critical state of erosion and in a climate showing wide departures from normal (i. e., high variability) is the Colorado Plateau. While the rainfall is comparatively small, less than a third of the area is in forest of light type, and concentrated showers increase the erosion potential to a level far above that of most areas of heavy rainfall. Sheep, goats, and cattle[13] have been grazed in all parts of the region and the forage has been diminishing at an appalling rate during the past few decades, with local deforestation and fire adding their effects in some degree. A reduction of plant cover, ranging from 33 to 60 percent, has been effected on grazed areas and a heavy reduction is noted also in the burnt and excessively logged areas. Tufted fibrous-rooted grasses have been partially replaced by single-stemmed and taprooted plants which are less effective in diminishing run-off and erosion. Overgrazing everywhere takes the low perennials out of the plant associations, and thus removes the protective undergarment of the plant cover. The thinner the perennials become, the greater the trampling effect, as animals have to move more widely. This invariably increases the erosive effect.

These effects are largely concentrated in the valleys and around settlements, partly because the pastures are more accessible there and partly because stock in the earlier days was subject to Indian depredations and had to be kept within reach. This concentration begins the incised form of erosion in many instances and, from local foci, gullies spread widely. Wagon roads and logging slides break down the natural vegetation, groove the surface, and concentrate the effects of run-off. Nature was here in a state of delicate balance and needed every resource she had to maintain the plant cover interactively with the soil.

We cannot always measure all of the forces that tend to create erosional unbalance. If the land is slowly rising or changing its gradient through forces within the crust of the earth we cannot tell how fast or how far it will rise or if it will continue to rise. We cannot halt the action of diastrophic forces in the earth's crust; but we can, by overgrazing and fire and forest cutting, anticipate their destructive effects by thousands of years. In like sense we cannot make less or more rainfall. But we can control the amount of vegetation, in the sense that we can avoid destroying it when the probabilities point to exceptionally dry years. We can also determine experimentally on small plots what will happen to both soil and vegetation when we remove or deplete the vegetation; and the evidence from this source is already completely convincing.

While we need more evidence from many other areas to determine detailed management practices, what we have already gathered shows that the next major step is control of vegetation right through its entire range, from small to large, and through groups of wet years and groups of dry years in succession, on every watershed where the experimentally determined erosion potential is high or erosion has already begun. This is the one known way of halting or reducing destructional processes on land with a natural cover of vegetation. Other forces, too, may be variable, but we can do nothing about them. Let us suppose that they were once in delicate balance with the vegetation. We can, if not too late, restore that balance. This is a concern not merely of the sheep herder and the cattleman, but also of the forester and the man who irrigates a field lower down the valley or who, as engineer, constructs a dam to impound water for irrigation and power development and

[13] Bailey, R. W., Epicycles of Erosion in the Valleys of the Colorado Plateau Province. *Journal of Geology*. 43 (4): 337–355, illus. 1935.

studies discharge figures, evaporation rates, and, especially, the rate of silting behind the dam. Irrigation enterprises in the United States already represent a national investment of 6 billions of dollars distributed over every watershed of consequence in the West.

We have spoken of "the balance of nature", but the phrase applies only to those places where degradational forces have been long at work and vegetation has had full opportunity to migrate into the area and become adjusted throughout the whole range of its distributions to water supply, soils, and slope exposure. Elsewhere, nature is striving for balance, if we may use an anthropomorphic expression. It is as if the soil invited plants to take hold and delay its march to the sea or to interior basin floors. The moment vegetation does take hold it tends to increase the amount of humic material in the soil, to make a better soil. It also increases the degree of slope upon which the soil may remain virtually at rest. All topographic profiles may then be steepened without increasing the rate of soil removal; or, if they remain at former grade, the rate of soil removal may be slowed down to the point of maintaining a normal soil profile in permanent form.

Conditions in the Wasatch Mountains point the truth and the moral. This is one of the growing mountains of the West. Its western face has an oversteepened profile; and alluvial fans of the Bonneville period of higher lake level are broken and faulted in a number of conspicuous places in response to further and relatively recent displacement of the underlying rock. Here the upward thrust of the crustal forces has long made it difficult for the soil to remain in place or to waste at a sufficiently slow rate to permit the maintenance of a proper soil profile. But the fact is, in spite of these handicaps, the forces did maintain themselves in balance. How long they would have done so, we do not know. We do know that the depletion of the range grasses touched off the growing unbalance.

Between Ogden and Salt Lake City [14] there are 15 canyons that have suffered floods during the past few decades. All of them originated on overgrazed, privately owned range land that constitutes but relatively small portions of the watersheds in question.

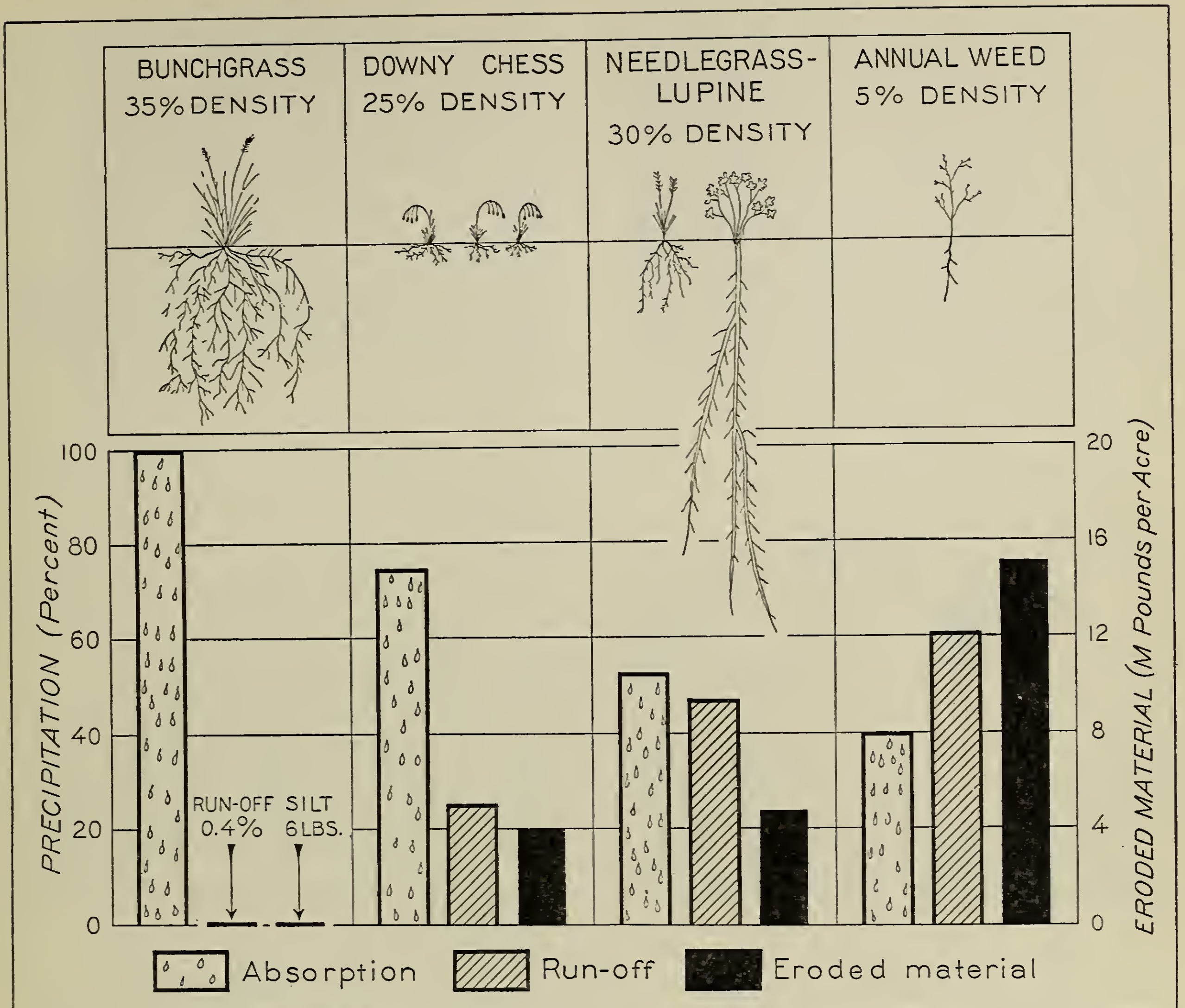
From a comparison of the deposits at the mouths of the canyons it has been determined that such floods (and mud-rock flows) have not poured out of these canyons for thousands of years. In 1932 at least 27 important watersheds in Utah produced destructive floods; and it has been found that the impelling conditions originated largely since settlement. Depleted range lands were the principal sources of the flood waters. Floods in some volume have doubtless occurred throughout the history of every watershed; the condition that alarms is that the number and intensity of floods have increased so rapidly and to such a point that they are now a major destructive force.

EXPERIMENTAL OBJECTIVES AND RESULTS

The mechanics of the process of delaying run-off and soil removal are not sufficiently well known. The degree of intensity of the process and the potency of the individual factors remain to be determined from subregion to subregion as a basis for detailed range, forest, and farm management. There is no doubt, however, about the principles involved. To take a single example: [15] Studies have been made on the Boise River watershed in Idaho on four plant types—annual weed, needlegrass-lupine, downy chess, and bunchgrass. A portable apparatus provided "rain" of controlled intensity that fell upon granitic soils having varying degrees of slope. Figure 34 shows the result. The bunchgrass, with its fine, ramifying root system, provided maximum absorption and least run-off and erosion. Percolation is promoted by the

[14] U. S. Department of Agriculture, Forest Service. See p. 306 of the reference cited in footnote 6.

[15] U. S. Department of Agriculture, Forest Service. See pp. 318–319 of the reference cited in footnote 6.



THE MOST DESIRABLE FORAGE PLANTS ARE COMMONLY THE BEST WATERSHED PROTECTORS

FIGURE 34 *The Western Range*

widely branching roots of the bunchgrass. Table 7 shows the effects of alterations of slope. Bunchgrass is the most efficient soil binder and protector. It is also the most palatable of the four, and, therefore, the first to be depleted on unmanaged ranges. The other three types decline in watershed protection value at about the same rate as they decline in forage value.

Most of the stream flow that provides water for irrigation, power, and domestic use comes from delayed run-off; that is, the melting of snow and the discharge of springs. Seeping through the soil and rock mantle, delayed by millions of grass stems, roots, and ground litter, these tiny ultimate sources provide stability of flow. On typical California soils Lowdermilk[16] found that the destruction of the surface litter by

[16] Lowdermilk, W. C., Influence of Forest Litter on Run-off, Percolation, and Erosion. *Journal of Forestry* 28 (4): 474–491. illus. 1930.

burning increased run-off from 3 to 16 times and increased erosion by as much as 1,200 times. The trampling effect of overgrazing is well known throughout the West. By this process vegetation is not only destroyed in place but the ground is packed hard, the capillary tubes broken, the humus is more rapidly oxidized, and the litter broken or washed away without the protection of impeding grass stems. Again and again this process has been reversed on experimental areas until the effects, the causes, and the cure are perfectly well known in principle. Floods began in the Manti region, Utah,[17] in 1888, and were followed by others more devastating—the result of more than 30 years of overgrazing. As soon as regulated grazing came in with the creation of the Manti National Forest, rehabilitation began, run-off was reduced, and there have been no floods of

[17] Forsling, C. L., *A Study of the Influence of Herbaceous Plant Cover on Surface Run-off and Soil Erosion in Relation to Grazing on the Wasatch Plateau in Utah.* U. S. Department of Agriculture, Tech. Bul. 220, 72 pp. illus. 1931. (See p. 3.)

Table 7.

Cover type	Run-off [1]						Average [4]
	Slope		Soil		Rainfall [3]		
	30 percent	40 percent	Undisturbed	Disturbed [5]	Low	High	
Bunchgrass	0.5	0.3	0.5	0.3	0.4	0.4	0.4
Downy chess	12.2	38.7	23.4	27.6	16.5	34.5	25.5
Needlegrass-lupine	55.6	44.3	49.7	40.1	41.6	54.5	47.6
Annual weeds	56.0	65.6	58.2	63.4	57.2	64.4	60.8
Average [6]	40.0	37.2	32.8	32.8	28.8	38.4	....

Cover type	Erosion [2]						Average [4]
	Slope		Soil		Rainfall		
	30 percent	40 percent	Undisturbed	Disturbed [5]	Low	High	
Bunchgrass	6	6	6	6	6	6	6
Downy chess	395	3,640	939	3,095	578	3,456	2,017
Needlegrass-lupine	4,660	4,874	3,359	6,320	2,960	6,573	4,791
Annual weeds	4,790	25,770	12,006	18,554	12,976	17,584	15,280
Average [6]	2,508	8,573	4,078	6,994	4,139	6,905	....

[1] Percent of rainfall applied.
[2] Pounds per acre.
[3] Low equals 0.03 inch per minute for 60 minutes. High equals 0.06 inch per minute for 30 minutes.
[4] Each figure represents the average of tests on 12 5-milacre plots.
[5] Artificial disturbance of surface to simulate trampling by livestock.
[6] Each figure represents the average of tests on 24 5-milacre plots.

consequence since 1910, in contrast to flood conditions where uncontrolled grazing has continued.

To lay a scientific basis for generalization respecting run-off, floods, soil erosion, and stream flow in relation to vegetative cover, thousands of plot studies have been made by different services of the Government, principally the Forest Service. Under controlled or selected conditions, standard measurements and notations have been made according to tested techniques of observation and record-keeping. This tells us rather exactly what happens and why it happens, as conditions are varied to determine the effect of each change. The procedure is analagous to that of the physicist in the laboratory. Just as the physicist then turns to engineering for mass application of his findings, so the forester must apply the results of his small plot studies to whole watersheds. When he does this he can no longer claim high accuracy, as in plot studies, because the conditions are almost infinitely variable. Inferences and approximations, therefore, take the place of close determination. This distinction has to be kept in mind when we turn from experimental results to field applications. It must also be kept in mind in planning future research that is rightly intended to increase the accuracy of the scientific findings that are, in turn, the indispensable bases of administrative action.

In the dryer parts of the United States it is not the local rainfall that is the chief source of water supply for towns and farms, but the flow from streams that rise in distant mountains or uplands. Of the 4 million acre-feet [18] of water diverted into the irrigation systems of Utah, 80 percent comes from over 10 million acres of watershed above 7,000 feet elevation. This means that the present annual investment of $3 per acre-foot in water shows a yearly net return in water value alone of about $1 per acre for every acre of watershed, without including forest or pasture values. About 99 percent of the electrical energy developed in the State is from generating plants located at the base of steep mountains. In the Intermountain Basin, between the Rocky Mountains and the Pacific Cordillera, a million people depend upon mountain sources for 80 percent of their water supply. The growth of irrigation facilities is closely correlated with the growth of population. Irrigated land has from 50 to 100 times the value of the adjacent unirrigated range. Above the valleys and basin floors and fringes is a foothill zone of grass of high grazing value oftentimes overgrazed and rapidly eroded under the impact of summer storms, to the detriment of irrigation works in the lower lands.

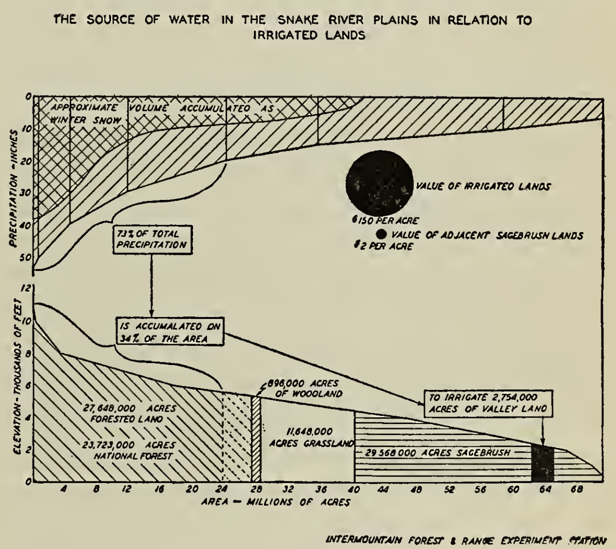


FIGURE 35.

In the Snake River plains of Idaho,[19] it is estimated that 73 percent of the total precipitation (fig. 35) is accumulated on the higher 34 percent of the area of the watershed that is forested. This is due partly to the location of the

[18] U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, *The Water, Erosion, and Range Problems in the Intermountain Region.* 106 pp. 1936. (Unpublished manuscript.) (See pp. 61 to 66.)

[19] U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. See p. 9 and table 8 of the reference cited in footnote 18.

zone of maximum precipitation which makes the forest possible, and to the snowfall and delayed run-off at forest-zone elevations. Snow surveys at elevations of 7,000 feet and more in the Boise watershed show that the average water content of the stored snow is from 25 to 50 inches when measured just before melting. During the season of snow from October through March there is received, even at elevations of 4,000 to 5,500 feet, two and a half times as much precipitation as on adjacent farm lands at lower elevation.

The engineering problem involved is to conserve the accumulated winter precipitation and deliver it to the land during the summer season of crop growth. The May discharge of the Ogden River, Utah,[20] exceeds the June-July discharge 30 times (1,500 cubic feet per second versus 50 cubic feet). During the growing season in the Boise watershed (April to September, inclusive) the farm lands of the valley receive less than 4 inches of rain, an amount that is inadequate to support any type of cultivated crops under the conditions of climate and soil that prevail there. During the peak-flow period,[21] from April 1 to June 24 (average dates), the Boise stream flow is constantly above the required diversion, while it is constantly below from June 24 to August 22. During the latter interval, stored water is drawn upon progressively until the reservoirs are completely drained before the end of August. The water wasted during the high stages of the river is more than equal to the mean annual shortage.

Almost half of the water deficiency, from the practical crop standpoint, would be met if the discharge of the river could be delayed 10 days, since that would delay the beginning of the period of deficiency until July 4, and storage water would be available until September 9. In this one valley alone the beneficial effect of such a delay would be of the order of $2,000,000. The cost of adding storage facilities to conserve peak flow would double the barely supportable cost of those that already exist. For a practical, that is an economical solution, we must, therefore, turn to watershed management through control of the vegetation, the forests, and the range grasses. By "control" we mean the elimination of abuse and dependence upon "the generally inexpensive measures of nature rather than * * * the costly constructions of mankind."

Experimental plot studies [22] clearly show that it is possible to increase the amount and rate of surface-water absorption by favoring the fibrous-rooted plants, the roots supplying additional and highly effective channels of penetration. Once water is absorbed, its time of delivery is delayed (in contrast to "flash" or flood run-off), the rate of delivery is slowed down (with reduction of waste), and the period of delivery is prolonged (when crops need it most). These are the effects we have in mind when we say that the water table should be progressively raised rather than progressively lowered, as at present, through gullying following overgrazing or through improper agricultural practice. A further beneficial effect would be to restore the soil to an earlier and better condition which, in turn, would have a reciprocal effect upon the vegetation. The silting of ditches and the filling of reservoirs with unwanted and eventually destructive sediments would also be greatly diminished. Experimental studies [23] in the Wasatch Plateau show that a chiefly herbaceous plant cover of 40 percent permits but 36 percent as much surface run-off and 46 percent as much soil erosion as a 16-percent plant cover.

When erosion of the soil takes place at a rate that markedly exceeds the building process, there is set up not mere erosion of so many inches

[20] U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. See pp. 9 and 67 of the reference cited in footnote 18.

[21] U. S. Department of Agriculture, Forest Service. See pp. 333 and 334 and fig. 73 on p. 333 of the reference cited in footnote 6.

[22] U. S. Department of Agriculture, Forest Service. See p. 318 of the reference cited in footnote 6.

[23] Forsling, C. L. See p. 70 of the reference cited in footnote 17.

per unit of time but the differential erosion of the separate soil particles or chemical constituents. Colloidal material, together with nitrogen and organic matter, go first, leaving coarser material in place so that the fundamental structure of a soil is changed through excessive loss of the surface material. The effect is not merely the loss of an arithmetical surface fraction of a homogeneous mass. This structural change means not only loss of fertility but loss of water-holding capacity. Once this fundamental change for the worse is really understood, it will be clear that from social and economic standpoints as well as from the scientific standpoint the loss of fertile soil through wrong tillage methods or the destruction of the vegetation (that may hold the balance of power among the erosive forces) is a loss that is not merely to be deplored; it is a loss that in places is already calamitous in extent and in intensity of local effect.

Time sense is lacking in a man who will not wish to take corrective measures now instead of letting things slide until the loss is permanent and nothing remains but the historian's analysis of the causes of ruin of one region after another. Moreover, the present is not the time of imperial Rome or China, when soil science did not exist, but the "age of science." So far have observation and experiment gone that we can now definitely forecast the evil effects of further neglect of the cause-and-effect relations. The problem has shifted from knowing to doing, and between the two is a gap that calls for a new intensity and a higher type of citizenship. Will the age of science produce these qualities?

In the study of forests as watershed protectors we still require experimental studies and comparisons. The problem is not to get the maximum amount of water out of a watershed but to get what we want when we want it. The retardation of snow melting in the spring is a "want" under all conditions of use. From a week to a month is the period of retardation in forest, the duration depending upon amount of snow, elevation, wind exposure, sunshine, and forest type. Each region, in fact each watershed, is a law unto itself. In many places the best way to "control" the protective elements may be to take the vegetation as it is, whether forest or grass or chaparral. Such a cover may represent nature in balance, with soils and vegetation interdependent and intercreative, if we may so phrase it: The vegetation supplying part of the food of the soil flora and fauna besides assisting the physical and chemical disintegration of rock and soil, promoting water percolation through root penetration, and blanketing the ground with litter that retards run-off.

What is natural is a question that must be answered before we can ask how far may we control nature. The first law of control in many areas is to preserve the natural. In general, and recognizing that soil erosion is not limited to steep slopes, we only extend the gully system and swell the area of abandoned land when we cut down the forest on slopes that exceed 10 to 15 percent. In the Appalachian Region [24] flood-flow studies were made by the Forest Service in 1934–35 on 23 small watersheds. The average maximum flood flow for all forested watersheds amounted to 38 cubic feet per second per square mile, while for grassed and abandoned agricultural land the figure was 432 cubic feet and for completely denuded land 1,304 cubic feet.

There are no uniform laws of forest effects upon run-off rates and totals. What is true in Maine may not be true in Nevada. We cannot say that forests of every type everywhere increase the rainfall, supply water more uniformly than other forms of cover, and increase the total run-off from watersheds. They may locally or indirectly increase the rainfall by small amounts; shrub or elfin forest may be as good a cover as true forest in some districts; the total run-off would undoubtedly be greater from a bare sur-

[24] Munns, E. N., and Sims, I. H., comps., *Forests in Flood Control.* 70 pp. 1936. (U. S. Cong., 74th, 2d sess., Sup. Rept. to Com. on Flood Control on H. R. 12517.) See p. 31.

face without the well-known transpiration effect of forests. In a laboratory experiment each factor may be isolated; in the forest, isolation of factors is impracticable except on a small scale and with approximate, not exact, results. The factor of evaporation varies enormously between 4,000 and 9,000 feet (or between upper and lower tree lines) in a single watershed. Stream flow is a variable made up of variables. A shower on a mountain range in the West may have less immediate effect upon soil moisture and run-off than an afternoon cloud cover in the East.

In Natal, South Africa,[25] the combinations of slope, rainfall, habit, soil intake, and isolation are such that the growth of exotic trees promotes soil erosion (by the suppression of the natural grasses). The wide-spreading root systems of the pioneer trees kill off the grasses, the soil begins to erode, the roots of the trees are then exposed, the trees are easily blown over, and soil erosion is given further stimulus. All of these factors and relations are summed up in slope, soil, run-off, and advantages and disadvantages of each type of natural cover under the specific conditions of a given place. These conditions constitute a series of pluses and minuses. They must be added together and the result observed as a whole. The results of detailed experimentation can be interpreted only in part. There is nothing uncertain, however, about the need for experimentation in a region where soils erode destructively and stream regimens grow worse.

GAINING POWER OVER THE OBJECTS OF STUDY

Knowledge is not gathered merely for the pleasure of those who gather it. It is not as a contribution to the meditative life that a long series of observations and experiments have been made by the Forest Service, the Geological Survey, and other scientific bureaus of the Government with respect to our natural resources. Observations have been made and experiments performed in order to try to determine cause and effect. Once that is done there is a chance that some degree of molding or guiding power may be exercised over the object of study. It is desired, through control, to eliminate needless waste and put resources to the best possible long-range and wise uses, if we can agree on what is wise within given limits of time and purpose. The peculiar task of our age is the turning of knowledge into dynamic power on a large scale. Our age has grown so complex in organization, and knowledge has grown so vast and pervasive, that broad national purposes have not been able to keep up with definitely discovered vital needs. What is required is a sense of public participation in the application of scientific principles, and the fashioning of new or more efficient organs of control. The condition of our range lands is a case in point.

Two generations of persistent search by homesteaders disclosed all of the best sites for permanent occupation (chiefly agricultural) within the knowledge and limit of means of the individual settler. The consequence was that progressively the poorer grasslands were left in the hands of the Government, if we exclude those that lie within the boundaries of the national forests. This means that overgrazing has grown in both tempo and intensity precisely where the grassy vegetation is thinnest and most short-lived and where destructive effects are greatest and most lasting. In New Mexico the peaks in number of livestock on the range have corresponded with the droughts of the past 50 years. In Utah today there are not more than a dozen well-cared-for private ranges. It is estimated that to reach safe and permanent grazing capacity there is required a 38-percent [26] reduction of livestock on the whole western range area and a 43-percent reduction on that part of it which lies in the public domain.

[25] Bayer, A. W., The Relationship of Vegetation to Soil Erosion in the Natal Thornveld. *South African Journal of Science*, 30: 280–287. 1933.

[26] U. S. Department of Agriculture, Forest Service. See table 82, p. 508, of the reference cited in footnote 6.

This means conservative grazing all the time and severe limitation of grazing in drought years. It also means action without loss of time. Over 100 million acres of range lands [27]—a total equal to the corn acreage of the entire country—have already been so abused by grazing that most of the fertile topsoil has gone, and it is this topsoil that largely conditions both moisture content and nutrition value. On more than a third of this vast acreage destruction has been desertic in effect, and it will be necessary to reseed the range if we wish to restore it in this generation. At best this will take from 25 to 50 years, judging by experiments in Montana, Colorado, and Utah; and it is an expensive process, in general exceeding the value of the land.

The objectives of a sound range policy should be permanently realizable wealth. To obtain them we need both intelligence and desire in stockmen and legislatures. The existing situation requires, among other things, the following: (1) Extension of the geographic distribution of the best range plants, the breeding of new range grasses or other palatable plants, and the further importation of drought-resistant and short-cycle plants from the Old World and elsewhere; (2) improved reseeding techniques so as to reduce the cost below the value of the land; (3) regionalized and seasonalized grazing practices so that grazing will bear a known relation to the plant cycle; (4) water storage and water recovery placed in a rational relation to grass by closer spacing of indispensable wells and reservoirs wherever the ground-water conditions permit; (5) elimination of uneconomic "mosaics" of small holdings of both private and public land; (6) a realistic relation of the program to freight rates, production, market limitations, and prices; and (7) everlasting attention to priorities of need and danger and recognition of the overshadowing importance of common sense. The fanatic, the man who "redoubles his effort after he has forgotten his aims", has no place in such a scheme.

[27] U. S. Department of Agriculture, Forest Service. See pp. 504–505 of the reference cited in footnote 6.

The measure of destruction already accomplished is the measure of need for both action and speed with respect to the finding or the breeding of new grasses. Every reseeding operation should be checked periodically. Much is known but much more needs to be known about the ecology of grasses and their relation to a permanent soil profile where this is possible and to erosion, especially where the stands are light. Every new growth and every secondary succession should be studied not only for vegetative effects but soil effects. There are puzzling problems still to be solved with respect to grass distributions. Parallel strips of soil extending northeasterly through Texas mark differences of plant growth, forest and grass growing almost side by side for 300 miles on the black, waxy prairie and the Carrizo Sands, respectively, with both persisting across the boundaries of climatic subprovinces. Here climate alone is not the principal determinant of distribution. Do variations of soil structure mark significant differences of habitat that cause grass to grow here and not there, or do structure and porosity, and the resulting differences in responses of different soils to wet and dry changes, play the leading roles?

The gas content of the soil (particularly oxygen) may have an important influence. The microbiology may furnish indicators. We know that successive changes in surface vegetation are paralleled by changes in the soil microflora, and that the soil population varies both quantitatively and qualitatively with soil type and vegetational cover. In addition, we have variations in effect of any one of these factors when the others are in a certain combination. Bringing a vegetative cover back does not mean, therefore, back to a preconceived "normal", but back to an optimum for given combinations of natural conditions. For this we need to know many more fundamental things about grasslands, and some of them require long-range experiments of which a part can be done within the framework of a reseeding and restoration program.

Such a program need not be prohibitively expensive if we keep in mind that a field problem is solved by a series of approximations based on comparisons of so-called scientific or exact data. The field conditions of experimentation cannot be established with the precision and under the controls familiar to the laboratory technician. Moreoever, exact determinations for a whole unified area, such as a watershed, are not required, because exact control, such as the laboratory may provide, is neither necessary nor possible. We do our work better and with greater probability of success, however, if we have at least near-exactness with respect to the optimum conditions required for the attainment of a given end. Always there is need in the end for judgment compounded of science, experience, and common sense with respect to cost.

Every plant has a different exponent of use: One type of grass will stand much more grazing than another; one type of forest may be cut off more completely than another without endangering reforestation. What are the boundaries of each type? So, too, every soil and type of land surface has its own exponent of erosion if the vegetative cover is removed. What is the measured rate of removal upon given types? Before the grass cover or the forest cover is restored the soil may be gone. A vegetative cycle may be measured in decades, a given soil cycle in millennia. There is no use in inviting a tree to come back if we have destroyed its home. Superficially, soil and plant cover may seem to have a general resemblance throughout the semi-arid West. As a matter of fact, every watershed has its own distinctive combination of plant, soil, and climate. And it is the combination that must be determined before we can lay our hands on cause-and-effect relations. Management of watersheds before these cause-and-effect relations are established is cut-and-try. It may be useful and justifiable even so, but no one would argue that it is preferable to the rational or experimental method if the latter can be kept within practicable bounds of cost.

We point to variety of need, priorities of use, and objectives of control as a further indication of the uniqueness of each individual watershed. From the topmost point of every basin to its final exit—over alpine summits and slopes, gathering places of snow, zone of maximum precipitation, forest cover, and upland pastures, valley slopes, drainage ways, and basin floors with their stands of grass and shrub—there is a sequence of conditions in a cause-and-effect relation that calls for integrated intensive experimental study if the conservation ideal of continuous best use is to be attained.

Since all good cannot be attained in a moment, it is necessary in this practical world to set up priorities of importance. Full experimental programs should be designed for application to the three or four most critical watersheds (rendered critical through misuse) and principles of management set up that are appropriate to the combinations of factors that determine "best" use. Many of the data that have been gathered are illustrative rather than diagnostic with respect to particular watersheds. A watershed is in a sense an organism; that is, it is composed of parts that are in vital relation to each other. Both the parts and the relations of the parts are the objects of research that is designed to give eventual control or partial control. Vegetation plays a major part in that relationship, and it happens to be the element that man can control most quickly and to the widest extent.

No mature consideration of land-water relationships can be given without reference to aesthetic values. Enjoyment, as well as understanding, is now a moving force in the long-range care of our resources. Even understanding is not always attained through logic alone. Not all good emanates from rational thought. What are the things we value and what is significant represent inquiries above the plane of cause-and-effect or logical relation. Part of our aesthetic enjoyment of nature comes from ever-changing compositions of natural beauty and part from the sharing of it with wildlife. How to protect,

use, and enjoy our high or remote archipelagoes of natural beauty is a question that links in with the protection and enjoyment of birds and beasts whose company we desire. If they desert us or become extinct, we shall be constantly reminded that we have taken barbarous possession.

"When knowledge becomes too great for unity, we are lost." The unifying elements of watersheds have been described over and over again. The next step is to secure general recognition of this truth. Attention to the influence of vegetation alone will not solve the long-range headwater problems of water and land. We cannot break up a watershed problem into parts, look at the parts, and consider the problem as understood. Values and uses of watersheds as wholes have first to be determined. This is fundamentally a social question with aesthetic, economic, political, and educational aspects. After that comes the question as to how accepted values and uses are to be achieved. At this point science comes in, but science guided always by the practical considerations of cost. It is physically possible to build and operate an interesting modern city at the South Pole; but at what cost, and for what values and uses not attainable at a more reasonable cost elsewhere?

DISCUSSION

1. Forrest Shreve

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There is no case in history in which a very large area has been converted from the virgin conditions of soil, streams, and vegetation into conditions of cultivation and use as rapidly as it has been done in the settlement of the United States. It is difficult for us to picture the conditions that existed in the valley of the Potomac when Cecilius Calvert made the first settlement in it 300 years ago. The great trees, deep shade, heavy layer of humus and clear deliberate streams made a type of country of which we have now only a few remaining fragments. It is much easier for us to visualize the great changes that have taken place here in the forested States than it is to realize those changes that settlement has inflicted upon the lower and simpler plant covering of the plains and western deserts.

A cross-section of the United States from the headwaters of the Ohio River to the mouth of the Colorado River involves a progressive decrease in the annual rainfall from 38 or 40 inches to 3 or 4 inches and a gradual impoverishment of the natural vegetation. In the upper Ohio Valley the pinch of drought is rarely felt by the oaks and maples. In the lower Colorado Valley water for desert shrub growth is available only for 10 or 12 weeks in the year. As settlement advanced from the more favorable part of the country toward the less favorable part it was inevitable that agriculture and grazing should encounter the same belts of limiting conditions that had controlled the natural vegetation for many centuries.

The optimism of the pioneer, the patent opportunities for gain, and the mechanization of farm work have contributed to the broadening of the belt in which natural conditions have shown that agriculture is not permanently secure. Grazing, pushed westward by the expansion of agriculture, has likewise spread in area and intensity beyond the regions of profitable permanence. Many of the men with practical experience on western farms and ranges had foreseen the difficulties which now face us. Likewise, many of the men engaged in the study of our streams, soils, and natural vegetation have known for years that the conditions which we are discussing today were coming or were here. It is one of the manifest duties of the scientific man to foresee. It is not always possible, however, in questions of wide public interest, to make a mature foresight the basis for energetic public action and cooperation. I am sure that it must be highly gratifying to every man who has been working with the fundamental details of the water-soil-vegetation complex, or has been studying the evidences from

such work, to know that there is now a profound public interest in these questions and a determination on the part of the Federal Government to act advisedly and energetically in the direction of corrective measures.

The intimate relation between plant cover, soil stability, and constancy of stream flow has been so fully demonstrated that it may be regarded as one of the axioms on which the discussions at this conference are based. The network of interrelations by which these three elements are bound together has been well demonstrated in many pieces of work and has been clearly outlined by Dr. Bowman.

It is important for us to consider the character of the relation between these three elements as we extend our consideration over the 2,000-mile stretch of land which separates the headwaters of the Ohio from the mouth of the Colorado. In the Ohio Valley the rainfall is ample and the natural vegetation is heavy. Logging operations may deplete the forests and destroy some of the humus, but they still leave a protective cover which is better in controlling erosion and flood than is the undisturbed cover in the western part of the section under consideration. It is indeed remarkable that 100 years of settlement in the Ohio Valley have left the present conditions as good as they are. The reason lies in the character of the precipitation and in the fact that there is ample moisture for the rapid and luxuriant growth of plants. In the western plains greater damage has been done in a vastly shorter time.

In the lower drainage of the Colorado River there is an extremely delicate balance between the elements of the water-soil-vegetation complex. It is very easy to disturb the natural poise of any one of them. The return from a disturbed to a primitive condition is very much slower than it is under moist conditions. The torrential character of much of the rain, the expanses of bare soil between the scattered plants, and the characteristic slope of the stream beds are all conducive to "flash floods." It is undeniable that such floods must have taken place at varying intervals for thousands of years before white settlement. Heavy grazing has been shown to have accentuated these floods which, in turn, have increased the depth and extent of the stream channels. The conditions existing in desert stream channels have been exaggerated by settlement rather than caused primarily by it, and even under present conditions, such rivers as the Santa Cruz and San Pedro in southern Arizona show a strong tendency to pass through the normal alternating phases of trenching and then of broadening the trench in order to accommodate a slower meandering current. While floods are disastrous in the Ohio Valley they serve an important function in the most arid States by assuring the annual replenishment of ground water in their lower courses. Check dams now being built on the minor affluents of southwestern rivers will waste through evaporation much water that would be of use to the lower-valley farmers dependent upon wells for their irrigation requirements.

The soil of a forest or of a heavy stand of grass receives little of the direct impact of rain. At least in the early stages, the movement of rain water across the soil surface is slow and is impeded so as to promote penetration. General surface conditions in the desert approach those of seriously depleted forest lands or slightly depleted grasslands. Under these conditions, the movement of rain water is rapid and assumes the form of the "sheet flood" which is well described by McGee. Over much of the American desert the surface is thickly covered with gravel and small stones, which receive the impact of the rain. This surface covering retards the flow sufficiently to make the sheet flood an agency of deposition as well as of erosion, but scarcely enough to facilitate penetration. A desert area which appears to be devoid of soil will usually be found to have a deep layer of it beneath the surface litter of stones and gravel. Erosion will attack this protected layer only after something has happened to remove the stones, or to mix

them with the underlying soil. Ten cows walking in single file, or a trip out and back with a team may suffice to start erosion and the formation of a small gully. These gullies are short-lived, because they carry such a heavy load that they soon dam themselves up, but the restoration of the protective mulch of stones is an extremely slow process. The character of the soil on the western plains is such that erosion by water or wind does not leave a natural protective rock mulch, and the topsoil is lost more readily than it is in the desert.

Many of the rivers draining semiarid or arid areas carried large quantities of silt in their flood waters at the time of the earliest explorations in the West. Since then several agencies have been responsible for increased erosion or accentuated floods which have augmented the load of silt and coarser material which these rivers carry. In every project designed to check flood waters by the construction of dams of any size whatsoever the accumulation of silt in the impounded water becomes sooner or later a menace to the efficiency of the dam. The Gillespie Dam, on the Gila River, is an excellent example of the rapid conversion of an impounded body of water into a swamp.

It has become very obvious that the best means of flood control are those operating at the largest possible number of localities in the area which contributes most to the flood waters. Under virgin conditions, when every square foot of the catchment basin exerted a check to the movement of the run-off conditions were ideal. Operations already under way which seek to check flood waters in the largest possible number of spots are soundly conceived and of great value. The urgency of the need for flood control in many districts has directed attention first to the management of the stream channels themselves, pending the time when other operations on the upland will greatly aid these measures. We are prone to think that the importance of vegetation in flood control lies solely in the earliest stages of water movement on the upland. It is possible, however, to use plants on the edges of the stream channels or even in the beds of smaller streams, to exert a continuous check on the flood waters and to spread the deposition of silt throughout the length of the channel. The Asiatic tamarisk is an excellent shrub for this purpose, and has already spontaneously assumed this role in several rivers in the southwest. In lower California I have seen streamways carry the drainage of valleys as large as Delaware in which there was no runway for the storm water, but instead a broad floor covered with close-set tussocks of bulrush. On this floor there was apparently a close balance between deposition and erosion, but no sign of channel cutting.

In our consideration of the evil effects that have resulted from overgrazing we are prone to lay much emphasis on the fact that rain water runs off more rapidly to the streamways and takes too much soil with it. Fully as important is the failure of the rapidly moving water to penetrate into the soil and become part of the great reservoir upon which plants can draw for many weeks or months. The problem of restoring to the plants of the upland all of the water that climate affords is a task even more delicate and difficult than the direct control of floods.

Detailed investigations on the changes in moisture content of an alluvial soil to a depth of 12 feet have been carried on at the Desert Laboratory of the Carnegie Institution for 5 years in conjunction with measurements of run-off and of duration and intensity of rainstorms. In the upper levels of the soil the rain water penetrates and soon disappears, but at 6 feet, the moisture content remains almost constant from year to year. In the upper 6 feet of soil the average amount of water held is equal to the normal precipitation for 2 years. The existence of such reserves of water in an arid climate is of great importance in planning the restoration and maintenance of a permanent plant covering. Wherever it is possible to stabilize surfaces that are being eroded by wind or water through the agency of hardy plants, even if they

be of no value in themselves, it then becomes possible to attempt the restoration of the original plant covering, or the introduction of a similar one, with a view to the utilization of as much deep-seated water as the soil and locality afford.

We have much to learn from the technique used in New Zealand in establishing successful forests of Monterey pine on areas which were originally a waste of wind-swept sand, and from the work of the Russian station at Repetek, in the Kara-Kum Desert, where almost forbidding obstacles to agriculture are being gradually overcome.

In view of the variations in the mean annual rainfall in the Central States, it is difficult to place the western boundary of safe agriculture in the Plains region. Without strict regulation agriculture will taper off toward the West, just as the flora of the eastern Mississippi Valley gradually disappears as the Rocky Mountains are approached. The abandonment of agricultural land in the western plains gives the opportunity for development of grazing land. The rebuilding of the essential plant cover is one of the problems with which we are faced. The great regions of range land where little or no agriculture has been attempted have been so heavily overstocked that their carrying capacity grows lower year by year. Another problem of these regions lies in the establishment of a better balance between the natural increment of range plants and the requirements of cattle and sheep. A third problem arises in the Great Basin and the Southwest in the determination of the limit beyond which grazing is precarious and unprofitable. All three of these great problems have much in common although the precise manner in which they are worked out must be in accordance with the differences of soil, climate, and natural vegetation which vary within the limits of a single county.

The need for the application of remedial measures in restoring or saving our grazing lands is urgent. We must do as much as we can as soon as we can. So great is our concern that we would like nothing better than to be able to restore them over night. We are in much the same position as a man who has felled a 200-year-old oak in his lawn and then regretting the loss of its shade and beauty has decided that he would like to have it back again.

Our knowledge of the behavior of natural vegetation shows that both the growth and reproductive phases are at their best in the seasons of most favorable moisture conditions. Likewise more can be accomplished by restorative methods in periods of high or moderate rainfall than in periods of very low rainfall.

Over certain portions of our range lands, especially those lying in or near the national forests, the best measures to be taken are those leading to the restoration of the original condition of the range through the reestablishment of a plant covering closely similar to the original one. In areas which have been denuded of their native plants and have lost much of the topsoil it will be necessary in most cases to work indirectly toward the reestablishment of the original type of vegetation or introduce plant species new to the region. Local conditions and local requirements will determine the extent to which direct or indirect methods must be used and the extent to which native or introduced plants are to be employed. Wholly different methods will be required on lands which have been completely abandoned and on those where some grazing must be continued.

The planting and seeding carried out by the Soil Conservation Service on our range lands constitute vigorous and noble efforts to help matters. As applied to carefully selected localities in which the range is seriously depleted these efforts will be productive of great good. When we consider that 100,000,000 acres of our range need similar treatment we are deeply impressed with the stupendous task involved and with the number of years that will be required to plant and seed it effectively. In addition to these methods we must rely to a great extent on natural reproduction and growth. The most effective

method of restoring our ranges will be to use every possible means of aiding the vegetation in restoring itself. The processes of nature are slow, but it is nature that we are dealing with. We are impatient but we must remember that we have also been ruthless. We are being paid the wages of our own sin.

By vigorous action we can at least keep the condition of the western ranges from becoming worse than it is at the present time, and that in itself would be an important accomplishment. The forester measures the annual increment of a given area of timberland and plans for the periodic removal of a sufficient number of mature trees to equal the total increment of the forest for the period selected. This is precisely the principle that should be used in handling range lands, although it is much more difficult to apply it to them in actual practice. It is more difficult to estimate the forage resources of a range than it is to measure the increment of a forest. The seasonal incidence of rainfall profoundly affects the growth of grasses and browse plants, and the carrying capacity of the range may fluctuate greatly within a single year. It is at least easy, however, for the cattleman to decide whether his range is growing better or worse. His most difficult problem, of course, is to adjust the size of his herds to the capacity of his range as frequently as conditions require, and to provide rest periods for the range. These are the conditions that have led to the fencing of range country and to the realization that no cattleman can succeed on a small range in the more arid parts of the grassland country. It has been shown that it is very important to keep cattle off the range entirely during the period of germination of the grasses and during their earliest growth. It has also been shown by clipping experiments that if the grasses are eaten off at an early stage of growth they will stool out and form larger mats than if left ungrazed.

The intensive study of range plants and range conditions is vitally essential to intelligent management. As Dr. Bowman has said, "Every plant has a different exponent of use." Prolonged investigation of the behavior of the important plants will amply repay its expense. The effort to plant or reseed will have its greatest success in connection with plants that have already been studied and the habits of which are well known from both the scientific and the practical standpoints.

The grounds of the Desert Laboratory, at Tucson, Ariz., have been protected from grazing and trespass since 1906. Certain areas on the grounds were mapped 30 years ago, so as to show the location and identity of every plant. At certain intervals the areas are remapped. The last examination, in the spring of 1936, showed that the increase in the number of plants during the last 8 years had exceeded that of the first 22 years of protection. This fact is impressive in showing the cumulative effect of the processes of recovery and the lapse of time that is required for them to get under way. It may be justly argued that vegetational change is particularly slow under desert conditions. Shantz has described the six stages of succession which result from complete destruction of short grass in Colorado and has stated that 20 to 50 years are required for its full reestablishment.

We may or may not be concerned with the reestablishment of a type of vegetation closely resembling the original one. In much of the range country we find that the most palatable grasses and other browse plants are now reduced in numbers and that there has been a great increase in the small perennial plants which are never eaten by stock. On the Desert Laboratory tract it has been found that the 30-year period of protection has led toward the development of a plant covering which is very similar to the original one but not identical with it. Among the plants which have now returned in greatest numbers are the grasses and palatable bushes and also two of the small perennials which are never eaten. These vigorous plants which multiply with the depletion of the range

may therefore multiply when it is completely protected. They are one of the most serious problems of range management. An ideal situation would result if they were completely eradicated and their space and water requirements shifted to palatable plants. The eradication of these plants is a difficult problem, and it is very doubtful if it would be followed by a compensating increase in grasses and browse plants, at least in more than a small fraction of the range country.

On closer examination of the group of plants which have greatly multiplied on the overstocked ranges (such as *Gutierrezia*, *Isocoma*, *Artemisia*, and *Franseria*) we find that all of them are plants of relatively low-water requirement and with deep-root systems. Also they reproduce freely and the young plants have great tenacity of life. If they were edible they would be ideal plants for the range. At least they are performing a valuable service in the retention of soil and the checking of run-off. Among the introductions from other countries it may be possible to find plants which are palatable and also have the vigor and tenacity of these range weeds. Until such time as there is brighter promise in this direction, the management of the ranges must be directed toward as great an increase as possible in the native range plants of each section. The conditions of soil texture, soil moisture, and surface litter are not as good for these plants as they were originally. Seeding on a large scale in favorable years may be very helpful, but the success of the seedlings depends on the surface conditions and on the restraint of grazing more than it does on the mere presence or absence of the unpalatable weeds. Indeed the seedlings of many of the desirable plants will benefit from the shade of the undesirables and for many months will not come into close competition with them for soil moisture, on account of the depth of the roots of the weeds. Since nearly all of the unpalatable weeds are native plants it is not too much to believe that long periods of careful range management and the restoration of the original surface conditions will put them back in their former place as minor constituents of the range vegetation.

The reduction of erosion and the stabilization of stream flow will be most effectively and permanently accomplished by the restoration of the plant covering. Every effort made to solve the problem of the maintenance of our great range area of 728,000,000 acres will also be of fundamental importance in conservation of soil and control of water. The Nation is fortunately awake to the importance and urgency of the situation, and there is a high percentage of agreement among the technical advisers of the Government as to what should be done. Most of these practices for the control and management of range lands have been developed from the careful research and experimental work carried on over a long period of years by governmental and other agencies. The most important of all the facts brought out in the extremely valuable Senate document "The Western Range", recently prepared by the Forest Service, is the statement that there are now 70 percent more animals grazing on the ranges of this country than there should be. It is obvious that the first and most important thing to do for the betterment of our ranges is to get rid of 7,000,000 cattle and sheep.

There is much ground for optimism in the situation. Nineteen percent of the range country is alleged not to be suffering from erosion. Sixteen percent of it is reported to have improved during the past 30 years. The greatest needs to support a continued optimism are a thorough knowledge of range plants and their behavior, a thorough knowledge of the physical conditions under which they live, a strict control of the use of the range, and above all the exercise of patience rather than haste in the acquisition of fundamental knowledge, in the application of remedial and conserving measures, and in the administration of the manifold agencies through which the water-soil-vegetation relationships may be put in a condition of well-being for the benefit of our descendents for all time.

2. Walter C. Lowdermilk

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Dr. Bowman's paper is an important contribution to the literature on upstream engineering involving the conservation of soil and water resources. The essential harmony of the complex of factors which make up land resources, including soil, vegetation, and water, has been appropriately emphasized. Moreover, the necessity of treating the resources of a drainage area as a whole, that is, as a unit, in the problems of upstream engineering, has been properly brought into clear relief.

Dr. Bowman has laid his principal emphasis upon the influence of natural vegetation, such as forests and grass, on the regimen of stream flow and the conservation of soil. This leaves us the opportunity to call special attention in this discussion to the dramatic changes wrought in natural harmonies by clearing land of its native cover and the cultivation of such bared soils to necessary agricultural crops. We may then consider briefly the hazards of cultivation to the sustained use of soil and water resources in relation to successful upstream engineering.

Hazards of Cultivation

Soils must be cleared and cultivated; the insistent needs of the hosts of humanity compel it; and this even if the cultivation process harbors the seeds of soil destruction. If a nation will be provident, it must begin measures of conservation before its resources are too far gone. A starving farmer will eat his seed grain. Foresight in safeguarding the utility and existence of a resource must rest upon a full understanding of the nature and trend of processes set in motion by past and present use of such resources. Particularly is this true of soil and water resources now under consideration.

The full effects throughout the world of clearing and cultivation of lands to crops have often been obscured by conflicting and complicating factors; shifting populations have abandoned eroded or parched lands; famines, revolutions, and civil wars have occurred without a full examination of causes; climatic cycles have placed special stresses on the margins of subhumid climatic zones. Only in a comparatively small area of the earth's surface has permanent agriculture in tilled crops been achieved, although a shifting cultivation has spread over most of the land within temperate climates, as well as much of the tropics. As Dr. Bowman has well said, the denser human populations are found chiefly on flat or nearly level lands. Accelerated erosion induced by augmented and accelerated run-off, on sloping lands, drives agricultural populations finally to the level lands or to level terracing of slopes; but these adjustments in land use have gone on with little appreciation or understanding of the causes. The role of soil erosion in land settlement has not yet been adequately studied or understood; it may be found to have played a villainous role in determining the fate of past civilizations.

Agriculture has generally been exploitive of soil fertility, leaving behind ruins of wasted fields, less pervious to beneficent precipitation, and yielding greater ratios of run-off. The hazards of cultivation were recognized by many observers over a long period of time. George Washington gave instructions to stop gullies, and Thomas Jefferson advocated contour cultivation as a safeguard against soil and water losses. Not until recent times, however, have the hazards of cultivation been subjected to measurement. Experimental measurements are establishing information upon a scientific basis and furnish for the first time measures of the magnitude of both soil and water losses under some of the conditions prevailing in certain regions. Such comparative studies have disclosed the nature of the threat to permanent agriculture in the exploitive use of soil. They have also disclosed that part of the major flood menace resides in the cultivated and closely grazed drainage areas.

Soil erosion experiments applicable to crop lands begun by Duley and Miller in Missouri in 1916 and the soil erosion experiment station in Texas established in 1919, were forerunners of the system of soil and water-conservation experiment stations located by Bennett in 10 of the representative regions where erosion is a critical factor in agriculture. Experimentation in erosion on agricultural lands thus began as early as those on the national forests and has covered a wider range of conditions.

A summary of the results from these soil and water-conservation experiment stations will be given by Dr. Bennett in his paper before this conference. It will suffice for my purpose to cite the relative influence of several surface conditions of land on the coefficient of run-off. The following ratios represent a summary of data from individual storms of highest intensity thus far recorded at the erosion experiment stations. Obviously averages of all rains, light and heavy, do not express the extreme tests of intense storms, nor do they suffice for flood-flow computations.

The comparisons cited represent the approximate relative intake of similar soils under the following different types of vegetative cover. Surficial run-off from rains approximating an intensity of 2 inches in 1 hour was found to occur in the following order: From native forest, 2 percent; from grassland, 5 percent; from fields in close-growing grains, 25 percent; and from row crops such as corn and cotton, 50 percent. Run-off from fields in corn or cotton may be twenty-fivefold that from forests under intense rains. Thus these several conditions rank in reverse order as to rate of intake, namely, for forests 98 percent, for grassland 95 percent, for grain fields 75 percent, and for fields in row crops 50 percent. The most acute phase of the problem of land-water relationships in flood-control and upstream engineering resides in the sloping lands cleared for cultivation.

The full import of these dramatic differences is arresting. It seems at first thought improbable in view of the absence of similar effects in the channels of major streams. The apparent lack of continuance of the dramatic differences in run-off in small areas to large streams has created confusion in the conclusions of many students of the problems of floods and stream flow. This point has been discussed more fully by the writer in other papers. In a general way, the expected run-off per square mile diminishes as the size of a drainage area increases. For example, run-off per square mile for certain areas in the Mississippi Valley will exceed 2,000 second-feet for a single square mile, whereas the run-off for the entire Mississippi drainage is approximately 1 second-foot per square mile. This wide difference in run-off from small to large areas, dependent upon the diminishing percentage of contributing watershed with increase in size of drainage, obscures the progressive trends in run-off characteristics of small areas. The behavior of major streams can be used neither as a measure nor as a criterion of the conditions of infiltration or absorption on small areas. The nature of processes at work within a drainage may be known chiefly by the responses on small areas, i. e., at the beginnings. Similarly an estimate of the future condition of a landscape under agricultural uses must be inferred primarily from upstream phenomena. The downstream effects are resultants of a maze of interrelated factors which defy evaluation. For downstream flood-control works must be designed on the basis of probabilities of combinations of factors.

The nature of the hazard of cultivation of soils, which were once covered with a natural mantle of vegetation, is disclosed in the meaning or significance of the soil profile. A soil profile differentiated into its A, B, and C horizons, or commonly called topsoil, subsoil, and parent material, tells a long and important story. Generally the soil profile represents a chemical, physical, and biological adjustment to the prevailing climate, relief, parent material, dependent vegetative formation, and normal rate of erosion. The soil under natural conditions has,

for example, adjusted itself to the prevailing rainfall including the intensive rains that occur, and as well to the action of surface off-flow of unabsorbed waters. Drainage channels are the usual sites of bank cutting which represents the normal geologic erosion under the humid cycle. The regimen of waters under these conditions represents the primitive state of nature, which may be a more placid state than that following the cultivation of sloping lands.

Such soils, weathered to fine textures, have developed interdependently with a natural coverage of vegetation. When soils are cleared and exposed to strong prevailing winds or to the direct attack of rain and running water, an entirely new order of processes is introduced into a landscape. They are cataclysmic. In water erosion, the percentage of storm run-off is greatly increased, which in turn results in the washing away of unprecedented amounts of the soil itself. Erosion of an accelerated and generally of an entirely new order of surface wash is introduced. The surface storm flows sort the transported soil material, taking the fine particles in suspension and rolling larger fragments as bed load; and begin a process of silting and shoaling of stream channels, lakes, and reservoirs at a rate far in excess of the normal condition.

The bared condition of the soil makes it much more vulnerable to the variability in climate and precipitation than it was under the protection of natural vegetation. Extraordinarily intense and heavy rains cause striking effects in the amounts and rates of run-off and corresponding erosion of soils. Thus the hazards of indispensable cultivation become a real menace to the sustained use of soil and water resources.

It is believed that the principal reason for this hazard was found in a series of experiments by the discussor a few years ago. It was discovered that muddy suspensions which are created on a soil by rain and surficial flow are filtered out at the surface and tend to clog the pores and channels in otherwise porous soil profile, whereas precipitation waters which fall on soils covered by natural mantles of vegetation and ground litter, remain clear. In the latter case, interstices, pores, and channels into the soil remain open, so that the full storage capacity for waters of the soil profile may be brought into play. The soil together with the underlying rock formations after all is the greatest of all storage reservoirs except the oceans.

The rates of intake into this great water reservoir of the land are determined by the condition of the soil surface. A coverage of natural vegetation of forest or grass permits the soil to function to its capacity for absorption. But the baring of soils formerly protected by vegetation brings about the puddling or pore sealing effect of muddy suspensions, so that the rate of intake of water into a soil is limited by a thin layer of fine-textured material at the surface. This phenomenon applies to all types of land: forest, grass, and cultivated fields. It is moreover the baring of soils by cultivation which creates the greatest hazards to rates of infiltration of rainfall, and the greatest rate of surficial run-off.

This simple determining fact of the rate of intake of precipitation water by the surface condition of a soil is fundamental in all soil conservation, in water conservation and in sustained production in agriculture, as well as in upstream engineering. This effect is at a minimum on level lands, and increases rapidly with slope gradients. Accordingly the hazards of cultivation are augmented by degree of slope, until gradients are reached which are altogether too unsafe or dangerous for cultivation.

The hazards of cultivation exceed the hazards of forest management or regulated grazing of grasslands. It is then in the plowed areas and overgrazed lands where most may be done as measures in upstream engineering. Measures to offset the hazards of cultivation become then of first importance in a program of upstream engineering. Such measures will consist of:

(*a*) Restoring and maintaining favorable rates of water intake by soils, as temporary storage to

reduce flash run-off as well as to increase the effectiveness of rainfall.

(*b*) Nullifying the erosive action of unabsorbed surface flowage of waters, to prevent their accumulation in destructive gully washers, and the leading of such waters harmlessly into natural drainage channels.

(*c*) Prevention of soil wastage and the accumulation of erosional debris in stream channels and reservoirs.

(*d*) The establishment of base levels of cutting in natural and artificial drainage channels to stabilize banks of such channels.

Important strides of progress have been made by research and by demonstration of known methods in meeting problems of water control through prevention and control of erosion of the soil. To these Dr. Bowman has referred. But there is much yet to be done. Only a beginning has been made in evaluating the several factors which make up the complex problem of soil and water conservation on lands whose varied uses must be continued for supplying the needs of resident populations. Our measures of today will require progressive refinement to meet the needs of the growing intensity of use of soil and water resources. In fact permanent agriculture on the vast area of sloping lands, which must be tilled, will require adjustments and great improvements over present practices in erosion control.

3. Carl O. Sauer

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This conference deals with "little waters"—the first collection of raindrops on and in the ground and the first stages of their return to the sea. This concentration of raindrops to form running waters is probably the most fundamental aspect of land and water conservation. However, sufficient consideration has not been given to the place where these initial processes occur, namely, the slopes that lie above the stream courses. In virtually all cases these slopes have developed under a cover of natural vegetation, without knowledge of which, neither the slope and its component material nor the regimen of its waters can be understood. The loss of original vegetation has exposed such slopes to destruction and to the alteration of the hydrologic regimen. The protection of the slopes involves the return to an approximately equivalent absorptive cover. The following inquiries and procedures are suggested:

1. *Effects of full natural vegetation on infiltration, run-off, and erosion.*—The wilderness reserves of the Forest Service point the way to a Nation-wide project. There still exist in many parts of the country patches of representative uplands in something like virgin condition. There are other tracts, which, though partially altered by man, promise to reattain a condition nearly like the original if given protection. These remnants of primeval and near-primeval vegetation and surface are most precious and should be closely guarded. We should lose no time in acquiring such natural monuments which are representative of each natural vegetation region and every major upland surface form. Such wilderness parks are the first laboratories needed, in which the natural processes of weathering and transport, the normal development of soil and surface as conditioned by normal vegetation, may be studied. There will be no difficulty about outlining a comparative and cumulative program of inquiry, once an adequate number of such reserves is in existence. Then, and then alone, can we determine adequately the amount, rate of change, and diminution of our land and water resources.

2. *Natural recovery of vegetation-surface-water balance.*—Again the major problem is one of the selection of significant tracts, of their protection from fire and stock, and of watching their undisturbed and unaided recuperation. For most natural regions of the country we still lack knowledge of the reconstructive energy in the surviving vegetation. We do not know whether or how soon ecologic successions can restore the hydrologic balance or reduce surface wastage to

normal rate. In the national forests such knowledge is being developed, but how largely elsewhere? In how many places have the lowly plant pioneers been given a free hand to show what they will do? And in how many places is a record of such recovery being kept? This is first of all a problem of the semiarid and subhumid western lands, on many of which managed grazing has not stopped deterioration of range nor decreased destruction by run-off. But what record have we of the effects of complete protection of upper slopes where flash floods are incubated? Perhaps the desperately thinned ranks of the surviving plants can do a job of downstream engineering if they are provided refuge areas in which to recuperate and from which to advance downgrade. There are many available trial grounds in the West. The Zuni watershed might be one. The Indian reservation, hard pressed by flash discharges into its basin from surrounding denuded uplands, suggests an experiment that may have valuable economic and scientific results. We have many areas where planting or seeding is not feasible, physically or economically. Why not a national program of natural plant rehabilitation?

3. *Possibilities of plant introduction.*—The best speculative opportunity here lies in the Southern States. The need is both for winter cover crops and for summer pasturage. The Northeastern States have acquired from northwestern Europe admirable grasses and legumes which do not find southern weather and soils congenial. California, by accident, has become blanketed by Mediterranean plants, valuable for pasture and hay. Southern agriculture depends primarily on native American crops, late starting and restricted in growth to the warm season. These originally Indian crops were developed by cultivation in hills, a cultural trait that still persists in their designation as row crops. Surely there must exist in parts of the Orient and in Africa useful grasses and legumes that will meet the greatest deficiency of the South. Scientific agriculture has scored a brilliant success in the South by the introduction of Japanese and Korean lespedeza, plants transferred from a similar climate and similarly climatically conditioned soils. The moral is obvious: Plant exploration may secure guidance from the climatologist and the culture historian. The ancient native livestock economies of the African plateaus and of humid Mohammedan Asiatic lands may well conceal the forage plants that are necessary to the preservation of our South.

PART II

CONSERVATION PRACTICES BASED ON LAND-WATER RELATIONSHIPS

CHAPTER V

Management and use of forest and range lands

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WHAT can forest and range management contribute to the control and use of soil and water? Or, in the terminology of this conference, what can it contribute to upstream engineering broadly defined to include the conservation of land and inland water resources and their products?

In attempting to answer these questions for forest and range lands, it is fully recognized that other lands, and primarily those cultivated for crops, have an important place. But as a background, let me indicate the area in the forest and range category, with which this discussion deals. It falls but little short of two-thirds of our total land area of somewhat less than 2 billion acres.

It is generally conceded that regulation of run-off, whether by natural or artificial storage, constitutes one of the fundamental aspects of control and use of water. It is commonly recognized, also, that the most favorable stream flow is obtained when the earth mantle of the drainage basin has a high capacity to absorb precipitation.

Research is more and more conclusively establishing the fact that the capacity of this earth mantle to absorb water varies with the condition of the vegetation upon it, and that excessive run-off from the surface and accelerated erosion ordinarily follow overuse or destruction of the plant cover. Maximum yields of timber and forage and optimum conditions for wildlife and recreation depend absolutely on the maintenance of an adequate plant cover. Therefore, in the restoration and maintenance to optimum conditions for organic resources, the forester and range manager are also creating conditions favorable for regulated run-off and for water control and use.

It is not claimed that plant cover alone will control run-off adequately in all cases. The Mississippi River was in major flood stage when first seen by white men in 1541, long before there had been any cutting of timber or cultivation of land. We have proof, however, that floods have greatly increased in number and intensity since those early days. We have proof that natural factors favorable to absorption have been greatly reduced in many drainage basins of the United States as our natural resources have been exploited. We have an accumulation of evidence showing why and with what degree of intimacy the increase in floods and erosion and the increased depletion of forest and range cover are related. There is a growing accumulation of factual data to show that good forest and range management will largely decrease the menace of floods and the costly waste of soil erosion.

Our research is showing that forest and range management reduces excessive erosion and run-off from the surface mainly because it maintains the interacting physical and biological conditions that help to get water into the ground. This process is influenced by (1) a porous soil that permits percolation to the water table; (2) a supply of humus that prevents the clogging of soil passageways by fine particles of clay and silt, and that also absorbs some of the water; (3) a litter cover that protects the soil from the mechanical action of rain and flowing water;

and (4) the plant cover, that produces the litter, binds the soil with its roots, provides channels for water to pass through the surface soil, spreads and delays surface run-off, and intercepts and lessens the destructive impact of rainfall. With the wildlife supported by the vegetation, which may influence run-off and erosion one way or the other, I will not attempt to deal.

Deplete or destroy this plant mantle by overuse, and litter and humus are not renewed; the impact of rain and the rush of water from melting snow are unopposed, roots no longer hold the soil; unobstructed run-off sweeps away the accumulated litter, humus, and topsoil; silt is impacted in the soil pores, practically halting infiltration; water rushes down the slope directly into the streams; absorption, infiltration, and percolation to underground storage are largely nonoperative.

The function and importance of litter in maintaining absorptive conditions in the soil is shown by the laboratory tests in which 2 percent [1] of silt in water reduced percolation into an unprotected soil by 90 percent. Field tests show that rainfall filtered through litter and humus causes no such stoppage; in one series of such tests run-off from soil surfaces so protected was, at worst, 30 percent [2] and, at best, 6 percent of that on bare soils. Even on compact soil with 10 percent gradient,[3] forest litter cut run-off to one-half and reduced soil loss to little more than 1 percent of that on bare soil.

The plant litter and roots not only protect the porosity of the soil; they are responsible for much of it. They supply the food and shelter for a teeming soil life which helps to incorporate organic matter into the soil and so to insulate the soil particles from each other and accentuate natural soil cleavages and interstices through which water may pass. In this way a soil well-clothed with a vigorous grass, shrub, or tree cover becomes porous and absorptive. To maintain or to restore these conditions is a crucial objective of both forest and range management.

Investigations are also showing that plant growth shelters the soil and reduces evaporation. It holds the loose litter and humus from washing under torrential rains or a sudden snow melt. It slows up the rush of waters that the soil cannot absorb, and so prevents the formation of gullies which otherwise would gather and quickly discharge water from the slopes. With an adequate forest cover, snow will remain on the ground from a few days to several weeks longer than in the open. [4] In upper New York in March 1936, when heavy rainfall, deep snow, and warm winds combined to produce many floods and all snow was gone on the open fields, there were still 12 inches of snow in adjacent beech-maple forests.

The contrast between what occurs when cover is reduced or stripped off and the results when vegetative cover is protected or restored through management is strikingly brought out in many tests of surface run-off and erosion in

[1] Lowdermilk, W. C., Influence of Forest Litter on Run-Off, Percolation, and Erosion. *Jour. Forestry* 28 (4): 474–491, illus. 1930.

[2] U. S. Department of Agriculture, Forest Service. *The Western Range.* 620 pp., illus. 1936. (U. S. Cong., 74th, 2d sess., S. Doc. 199.) (See p. 323.)

[3] Munns, E. N., and Sims, I. H., Comps., *Forests in Flood Control.* 70 pp. 1936. (U. S. Cong., 74th, 2d sess., Sup. Rept. to Com. on Flood Control on H. R. 12517.) (See p. 10.)

[4] Ashe, W. W., Relation of Soils and Forest Cover to Quality and Quantity of Surface Water in the Potomac Basin. In *The Potomac River Basin,* U. S. Geol. Survey Water Supply and Irrig. Paper 192, pp. 299–335, illus. 1907.

Connaughton, C. A., The Accumulation and Rate of Snow as Influenced by Vegetation. *Jour. Forestry* 33 (6): 564–569, illus. 1935.

Jaenicke, A. J., and Foerster, M. H., The Influence of a Western Yellow Pine Forest on the Accumulation and Melting of Snow. *U. S. Monthly Weather Rev.* 43 (3): 115–126, illus. 1915.

MacKinney, A. L., Effects of Forest Litter on Soil Temperature and Soil Freezing in Autumn and Winter. *Ecology* 10 (3): 312–321, illus. 1929.

outdoor forest and range laboratories. Let me give examples of the effects of cultivation of watershed lands, of fires, and of unregulated timber cutting and grazing.

The severe Yazoo River flood [5] in Mississippi in 1931–32 followed 27 inches of rainfall within the watershed, an appreciable part of which had been cleared. Sample plots showed that 62 percent of the rain ran off immediately from cultivated fields and 54 percent from abandoned fields, but in scrub oak forests only 2 percent ran off, and under an undisturbed oak forest only 0.5 percent. In Wisconsin [6] an average of 3 percent of the total summer rainfall ran off beneath hardwood forests of varying density, and about 7 percent from wild pastures; whereas from cultivated hayfields the run-off was nearly 18 percent, and from fallow land, 25 percent.

Protection against fire is a practically universal requisite in forest management. Fire—even a light fire—reduces the ground litter and plant understory and may materially accelerate erosion and surface run-off. A hot fire often destroys the entire plant cover and consumes the litter as well as a large part of the soil humus. Destruction of the cover and humus reduces the ability of the land to absorb and hold a considerable quantity of water for evaporation, percolation, or transpiration. Serious acceleration of washing, gullying, and silting ordinarily follows.

Forest fires in an old-growth pine-hardwood forest in the southern Appalachians [7] increased surface run-off on an average by 10 times over that of unburned forests of the same type, and as much as 32 times in individual storms.

In the Sierra pine region a 5-year record [8] shows that surface run-off from repeatedly burned plots was from 31 to 463 times that from comparable unburned plots. The yearly erosion from the burned plots was 22 to 239 times that from the unburned.

During prolonged rains at Guthrie, [9] Okla., in 1930 the run-off from burned-over ground was nearly 28,000 gallons of silt-laden water per acre, in contrast to a loss of 250 gallons of clear water per acre from the same soil and slope under unburned forest.

The form and extent of timber cutting also materially influence surface run-off and erosion. During March 1936,[10] when some of the Tennessee tributaries reached flood stage, the maximum rate of discharge from a small drainage covered with hardwood forest was 18 cubic feet per second per square mile. From an adjoining clear cut drainage the maximum discharge was at the rate of 232 cubic feet, despite the fact that the basin had been partially reclothed with herbaceous cover.

One of the most common forms of poor range management is the attempt to graze more livestock than the range can carry. That range depletion inevitably follows has been conclusively shown. Tests on Boise River watershed [11] ranges in different stages of depletion and supporting different kinds of vegetation showed that typical bunch-grass virgin ranges, subjected to artificial rainfall, yielded only 0.4 percent surface run-off and but 6 pounds of soil per acre. Similar tests on overgrazed and depleted ranges averaged 45.4 percent run-off and 7,382 pounds of soil

[5] Meginnis, H. G., The Yazoo Flood and its Causes. *Amer. Forests* 38 (11): 592–593, 623–624, illus. 1932.

[6] Bates, C. G., and Zeasman, O. R., *Soil Erosion—A Local and National Problem.* Wis. Agr. Expt. Sta. Research Bull. 99, 100 pp., illus. 1930. (See table 10, p. 71.)

[7] U. S. Department of Agriculture, Forest Service, Appalachian Forest Experiment Station. *Fourteenth Annual Report and Program, Appalachian Forest Experiment Station, 1934–35.* 30 pp. 1935. (Mimeographed.) (See p. 14.)

[8] U. S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station. *Forest Research in the California Region 1933–34: Investigative Program.* 121 pp. and project outlines. 1934. (Typewritten and mimeographed.)

[9] Bennett, H. H., Relation of Erosion to Vegetative Changes. *Sci. Monthly* 35 (5): 385–415, illus. 1932.

[10] Unpublished results of experiments at the Appalachian Forest Experiment Station of the Forest Service, U. S. Department of Agriculture.

[11] U. S. Department of Agriculture, Forest Service. See table 56, p. 320 of the reference cited in footnote 2.

per acre. On the most severely depleted ranges, run-off from the equivalent of 1.80 inches of rainfall, applied at the rate of 1 inch in 16.6 minutes amounted to 60.8 percent; and soil was removed at the rate of 15,280 pounds per acre, or 2,500 times more rapidly than from the well-managed undepleted range.

This Idaho study substantiates the results of earlier research on range lands of the Wasatch Plateau [12] where, during the period 1915 to 1929, restoration of the density of the range cover to 40 percent from 16, by regulated grazing, resulted in a 64-percent decrease in surface run-off from torrential storms and a 54-percent reduction in soil loss. During the past 2 years treatment of the plots has been reversed, and already the run-off and erosion figures are verifying the effectiveness of increased plant density.

Small scale results are substantiated by tests on drainages of several thousand acres. The normal run-off from two forest and chaparral-covered watersheds in southern California [13] was measured for 7 years. One of the areas then burned over. In the next year, while the unburned area reacted normally, run-off increased 231 percent from the burned watershed and the maximum daily discharge increased 1,700 percent.

The disastrous flood of January 1, 1934, in Los Angeles County, Calif.,[14] corroborated the research findings on numerous experimental plots. About 12 inches of rain fell during 2½ days. From one drainage of 4,000 acres, nearly all of which burned a few weeks earlier, came a flood which destroyed 34 lives and caused damage estimated at $5,000,000. The maximum flood discharge from the burned basin reached 1,100 second-feet per square mile, and altogether about 67,000 cubic yards of eroded debris per square mile of watershed were carried to the valley. From a nearby unburned canyon, with the same precipitation, the peak flow was at the rate of only 50 second-feet of water and the debris discharge was at the rate of 56 cubic yards per square mile of watershed area. The run-off ratio was, therefore, about 22 to 1 and the debris ratio more than 1,100 to 1.

Results on large areas of poorly managed range lands parallel those from forest lands. In northern Utah,[15] beginning in 1923 and continuing to 1936, the steep Wasatch canyons have flooded with increasing frequency and severity. A single canyon flooded four times in the summer of 1930, destroyed several homes, piled boulders weighing up to 200 tons on orchards and truck gardens, and caused several hundred thousand dollars damage to valley lands and improvements. Intensive examinations proved conclusively that the floods originated on unbelievably small upstream areas denuded by overgrazing. The valley sediments gave unmistakable geological evidence that no floods comparable to those in 1930 had occurred in the 20,000 years since ancient Lake Bonneville receded from the valley floor. The volume of debris from these recent floods exceeded all that produced during 200 centuries of normal erosion and deposition.

During the past few decades floods of this nature have occurred in such numbers throughout the West, in the torrential rainy season, that the local western newspapers have carried almost daily accounts of loss of life and property damage from walls of water and mud flows originating on depleted range lands. Between Salt Lake City and Ogden, for example, 15 canyons on the Wasatch front have flooded seriously in the last 15 years.

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[12] Forsling, C. L., *A Study of the Influence of Herbaceous Plant Cover on Surface Run-Off and Soil Erosion in Relation to Grazing on the Wasatch Plateau in Utah.* U. S. Dept. Agr. Tech. Bull. 220, 72 pp., illus. 1931. (See p. 70.)

[13] Hoyt, W. G., and Troxell, H. C., Forests and Stream Flow. *Amer. Soc. Civ. Engin. Proc.* 58 (6): 1037–1066. 1932.

[14] Munns, E. N., and Sims, I. H., comps. See p. 23 and table on p. 24 of the reference cited in footnote 3.

[15] Bailey, R. W., Forsling, C. L., and Becraft, R. J., *Floods and Accelerated Erosion in Northern Utah.* U. S. Dept. Agr. Misc. Pub. 196, 21 pp., illus. 1934.

The primary justification for research is human betterment. How then shall we best apply on forest and range lands for the highest human good such findings as those indicated—and they are merely random selections from the rapidly growing number already available—together with other observational findings and the results of many years experience in actual forest and range management.

The application of such findings and experience in forest and range management has two great advantages. The first is the opportunity to attack the erosion and flood control problem at its source, to prevent enormously destructive forces from starting rather than to attempt to control them after they have been unleashed.

The second advantage is that the vegetative cover, whether range or forest, is the only natural factor that man can materially modify. Such other factors as climate, geological formation, and topography must be taken as they are.

One important phase of our application should be, through land planning, to draw the best possible lines between lands which should be retained in forest and range and those which should remain in cultivation, and as far as possible to correct mistakes and rectify maladjustments of past trial and error, and to prevent repetition of mistakes and maladjustments.

Further destruction of forest and range areas could be stopped and in most cases satisfactory watershed conditions restored and maintained by fire protection and nonuse. This, however, would needlessly deny all other uses for one. Watershed use is rightly multiple. It should yield usable supplies of water for industrial and domestic purposes, irrigation and navigation, and it should offer protection against floods rather than constant danger from them. But except for very limited areas it should also include the production and use of timber, forage, wildlife, and many other resources. It should provide essential recreational facilities. Permanent civilization depends upon the sustained production of these resources and services.

Continued full use of forest and range watershed land depends, however, upon a satisfactory balance between the destructive forces of erosion and the constructive processes of plant growth and soil formation. I do not mean that we should attempt to regain the exact balance of virgin forest or range, for that would ignore many demands of human use; but a balance that will maintain for wise use all the basic resources of the land.

In the arid and semiarid West the maximum yield of usable water is essential because water is the key to the entire industrial and social structure. The theory that on such watershed areas water-consuming plant cover should be eliminated will not hold. We have ample evidence that disastrous floods and erosion result from denudation. Many watershed areas are steep, soils are relatively thin, and with torrential rains and heavy snows the erosion and flood potential is critically high. The small gain, if any, in usable water would never compensate for the flood and erosion problem created by denudation. Forest and range management in the semiarid West must accept as a first consideration the necessity for protecting drainage areas from erosion and rapid surface run-off.

In humid sections forest watershed management to increase total water yields is largely unnecessary. But efforts to decrease high peak flows and if possible to increase low stream stages by all feasible forms of upstream engineering are a critical need.

More specific application of research findings and practical experience in forest management may for the purposes of this discussion be reduced to a few major operations: Protection against fire, reforestation, and methods of cutting and cultural operations in timber stands to increase the quantity and quality of the product and also the effectiveness of erosion control and stream-flow regulation.

On an average during the 5-year period

(1926–30),[16] some 41½ million acres of forest land were burned over annually in the United States. One reason for this excessive acreage is that 190 million acres,[17] largely on important drainages, lack any organized protection. A primary requisite is that organized protection be extended to this area. Watershed requirements as well as those of timber production make it essential also that the standard of existing protection on approximately 320 million acres [18] be raised as rapidly as possible.

Reforestation is a second major form of forest management. Any constructive program requires the rehabilitation of lands submarginal for agriculture. Such land is now under unprofitable cultivation or has been abandoned because erosion has removed the topsoil or because productive capacity is naturally low. A portion may be suitable for pastures and some, with protection, will reforest naturally, but the remainder will require planting. This in the aggregate might involve as much as 50 million acres.[19] An additional area of at least 10 million acres of cut-over and burned-over forest land will not reforest naturally within a reasonable time and should be planted to reestablish a watershed cover as well as for other purposes.

Much of our remaining forest area is only partially productive for timber growing and ragged irregular stands are not fully and satisfactorily meeting watershed requirements. Better methods of timber cutting and various other forms of management are called for. For example, about 10 million acres [20] of forest land were being cut over annually during the years immediately preceding the depression. Through a combination of cutting and fire, an average of 850,000 [21] acres annually were practically devastated and made subject to erosion and rapid run-off. On only a small part of the remainder were systems of cutting followed that were wholly satisfactory either from the timber culture or watershed management standpoints. The total area needing more intensive management runs into hundreds of millions of acres.

Unfortunately, mismanagement is not confined to our forest lands. The natural plant-soil-water balance [22] has been seriously disturbed on from 85 to 90 percent of the 728 million acres of range land. About 60 million acres of major water-yielding importance and an additional 292 million acres of low water-yielding capacity are contributing heavily to the silt burden of major streams and intensifying the problems of water use. Unsatisfactory conditions on an additional 237 million acres are aggravating the difficulties in local water economy.

By far the most important step needed to stop further destruction is the reduction of numbers of domestic livestock to a level which will start the range on the upgrade. This will require reduction of some 40 percent [23] in present numbers. Systems of grazing worked out by research and experience which will promote the reestablishment and maintenance of the natural plant-soil-water balance by natural revegetation should supplement such reductions.

As on forest lands, extensive watershed range areas are so seriously depleted that artificial reseeding will be necessary. About 38 million acres [24] need this treatment. After segregating all the land on which grazing may be continued,

[16] U. S. Department of Agriculture, Forest Service. *A National Plan for American Forestry.* 2 v., illus. 1933. (U. S. Cong. 73d, 1st sess., S. Doc. 12.) (See p. 44.)

[17] U. S. Department of Agriculture, Forest Service. See pp. 51 and 52 of the reference cited in footnote 16.

[18] U. S. Department of Agriculture, Forest Service. See table 2 on p. 1396 of the reference cited in footnote 16.

[19] U. S. Department of Agriculture, Forest Service. See p. 19 of the reference cited in footnote 16.

[20] U. S. Department of Agriculture, Forest Service. See p. 9 of the reference cited in footnote 16.

[21] U. S. Department of Agriculture, Forest Service. See p. 852 of the reference cited in footnote 16.

[22] U. S. Department of Agriculture, Forest Service. See table 58 on p. 325 of the reference cited in footnote 2.

[23] U. S. Department of Agriculture, Forest Service. See table 82 on p. 508 of the reference cited in footnote 2.

[24] U. S. Department of Agriculture, Forest Service. See p. 504 of the reference cited in footnote 2.

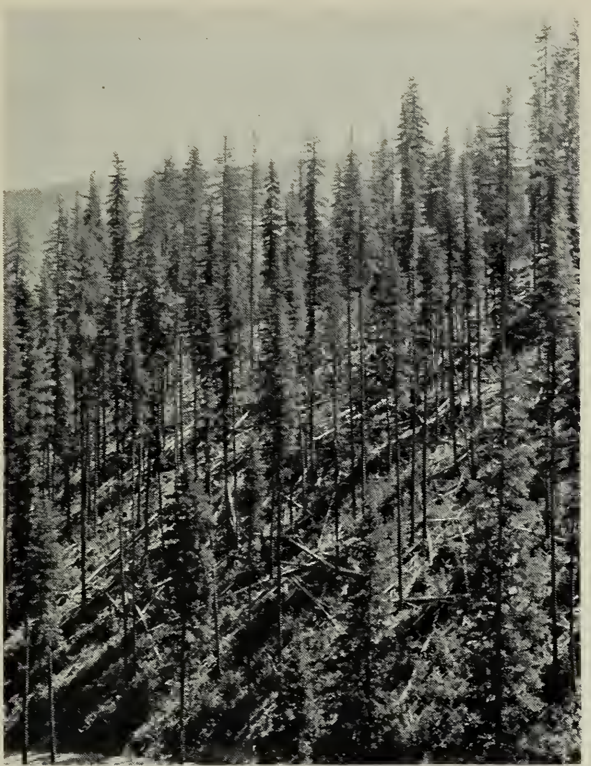

FIGURE 36.—Selective cutting.

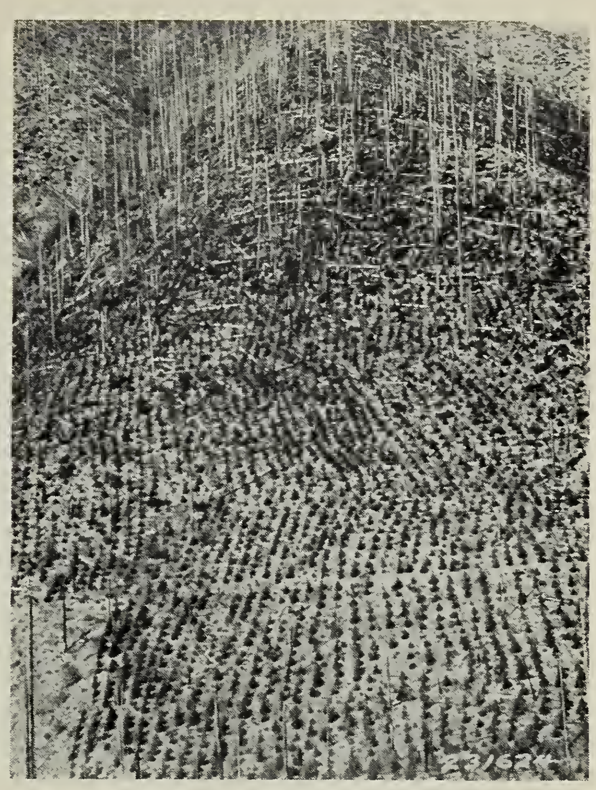

FIGURE 37.—Restorative planting.

FIGURE 38.—Typical terrace trenches on steep Utah mountain slopes.

PERPETUAL YIELD FOREST MANAGEMENT RETARDS RUN-OFF AND PREVENTS EROSION

U. S. Forest Service photos.

U. S. Forest Service photo.

FIGURE 39.—Accelerated erosion caused by overgrazing.

U. S. Forest Service photo.

FIGURE 40.—Conservative grazing is not detrimental to vegetative cover and watershed protection.

an area of some 11½ million acres[25] will remain on which, because of its critical importance in erosion control and water conservation, grazing should not be permitted. This area is characterized by such conditions as steep slopes or loose soils or difficult growing conditions. Usually such lands are submarginal for grazing so that nonuse involves no permanent waste of forage.

Engineering must play an extensive part in good forest and range management, and in the control and use of water. Temporary works, such as silt-holding dams and drainage terraces, are needed in many instances to make possible the restoration of plant cover.[26] Such structures as small reservoirs, retarding dams, the restoration of unwisely drained lakes and swamps, revetments, and other forms of bank control, spreading works, etc., should supplement what forest or range cover alone can supply in water and erosion control. Many of these will improve wildlife environment, increase recreational facilities, and provide small water storages for irrigation and small hydroelectric developments. Even in the high rainfall country engineering projects such as drainage pits and terraces to improve on the best that nature can do in the conservation of water may be desirable.

Land ownership presents one of the most difficult problems in a coordinated program of forest and range management. This is because of the long standing American philosophy that all land, regardless of its character and productivity, should be privately owned. It is also because each owner has been and is still largely free to manage his land as he pleases, regardless of how this may affect either the public interest or his own. Since the private owner may not be able to take needed remedial action or may not be interested, various forms of State and Federal cooperation have been devised and applied. In this field a big undertaking still lies ahead. Furthermore, the possibility should not be entirely overlooked that the American public may become sufficiently aroused to take drastic action to insure the management needed in the public interest.

Even though everything is done to encourage and assist such a program on private land, areas will remain on which satisfactory results cannot be obtained under private ownership. These include lands of especially high public value for flood and erosion control, or where the cost of maintenance of plant cover and necessary engineering renders the land submarginal for private ownership, or areas in such a stage of deterioration that individual enterprise cannot expect to rehabilitate them. Here State and Federal ownership must step in. A start has already been made by retaining in Government ownership a large part of the public domain in the West and by land acquisition. The best information now available indicates that it will be necessary to increase State and Federal ownership of forest lands in the entire United States by approximately 150 million acres, and of western range lands by 125 million acres.

Last but not least in any constructive program of forest and range management is the need for much additional research on all phases of management. This need should not delay action along the many lines for which workable information is already available, but provide instead for the increasingly intensive requirements of the future.

On the strictly watershed phase at least 25 major investigative installations or projects are required,[27] each including and ranging down from watersheds of several thousand acres to small sample plots and laboratory tests, and designed to ascertain for its own peculiar set of conditions all of the facts of the cover-erosion-water relationship. To meet the highly diversified conditions of cover, climate, soil, topography,

[25] U. S. Department of Agriculture, Forest Service. See p. 44 of the reference cited in footnote 2.

[26] Bailey, R. W., Shackling the Mountain Flood. *Amer. Forests* 41 (3): 101–104, 150, illus. 1935.

[27] Munns, E. N., and Sims, I. H., comps. See pp. 44–50 of the reference cited in footnote 3.

geological formation, and forest and range economy in the United States, at least 25 additional projects, less intensive in character, will also be required.

In order to obtain detailed information on existing conditions as a basis for appropriate planning and action, these projects must be supplemented by watershed surveys such as those provided in the recently approved Omnibus Flood Control Act.

The considerable progress already made on many phases of the watershed problem have not been overlooked and should not be minimized, even though time limitations have prevented more detailed reference in this very sketchy discussion of a future program.

Forest and range management constitute only one phase of upstream engineering. They must be integrated and correlated with all other phases. But taken alone they must deal with an enormous land and water resource and a wide variety of products and services. To carry out any program which measurably approaches our present and foreseeable future national requirements will challenge the best efforts of many scientific and professional groups, among which the forester and range manager, and the engineer, must take a leading part.

DISCUSSION

1. Clarence F. Korstian

Director, Duke Forest, Duke University, Durham, N. C.

It is especially fortunate that engineers, agronomists, geologists, geographers, and foresters can meet together and discuss problems from different angles and yet with common objectives. I would be very much interested in hearing the representatives of the engineering profession discuss the forestry papers as well as the engineering papers. Such an exchange of views should be very helpful in clarifying the problems and in arriving at a logical, cooperative solution of them.

Those of us who have studied the influence of the forest upon its environment will agree most heartily with Dr. Clapp that a cover of forest and range plants of satisfactory density contributes greatly to retarding the run-off of surface water and to the control of soil erosion and floods. We can also readily agree with him that the destruction of the cover of forest or range vegetation results in enormous increases in run-off, erosion, and in the frequency and severity of floods. This point has already been emphasized in the report by the United States Forest Service on the relation of forestry to the control of floods in the Mississippi Valley.[28]

The best of argument exists for the adoption of a permanent system of flood control. This involves, among other features, the acquisition of forest lands on which the restoration and maintenance of suitable forest conditions will aid in preventing and controlling floods at their source and also providing for the management of these lands.

I agree still further with the speaker that, because of the multiple use of much of the land on the headwaters of many of our streams, the most logical, long-time, land-use planning is needed. Dr. Clapp has very appropriately emphasized the importance of land management in an adequate program of upstream control of floods. In fact I would prefer to regard the problem as being one of upstream management rather than merely one of upstream engineering alone. The need is more urgent for a long-time plan in which engineering works on rivers and headwater streams and the revegetation and reforestation of their drainage areas are properly coordinated and weighted as to their individual and combined value for flood control. The erosion, run-off, and flood situation in the United States presents both a challenge and a unique opportunity for the engineers and the conservationists to work together in plan-

[28] Sherman, E. A., et al. 1929. *Relation of Forestry to the Control of Floods in the Mississippi Valley.* 740 pp. H. Doc. 573, 70th Cong., 2d sess., Washington, D. C.

ning and inaugurating a long-time flood-control program. I feel sure that I am safe in saying that the foresters will be willing to do everything within their power to cooperate in such a program.

Any long-time plan should call for a most careful coordination and integration with private interests of the activities of all Federal, State, and local governmental agencies. These plans should be carried out under voluntary cooperation and not under regimented coercion or compulsion. The results now being obtained by the Soil Conservation Service of the United States Department of Agriculture are indicative of what can be done through voluntary cooperation. On projects involving the control of soil erosion or of floods, the interests of all citizens should be fully considered, for in their role as taxpayers they will be obliged to contribute substantially toward the ultimate cost of all such projects.

The necessity of controlling waters at their source can scarcely be overemphasized. The place to apply the remedy in the control of soil erosion and floods, as in disease control, is at the source of the malady. Because of the fact that the most effective place to control floods is on the many small headwaters streams the utmost importance attaches to upstream engineering and land management. I daresay that if the vast sums which have been expended for flood control and for the relief of refugees rendered homeless in the lower Mississippi Valley had been wisely and effectively spent on the upper tributary streams and their drainage areas the flood-control problem in this valley would be far less serious than it is today.

Although immediate steps should be taken looking toward the initiation of a coordinated flood-control program, its completion will require many years of concerted action in order to achieve the desired results. We should not expect to remedy the entire situation within one or even two presidential administrations. The forces resulting in the present conditions have been at work for somewhere between 100 and 300 years.

A permanent organization similar in many respects to the present Civilian Conservation Corps could do much of the work needed on the headwater streams and watershed areas. If the C. C. C., one of the best of the unemployment relief activities, is to be made permanent as is being advocated in many quarters, such control work as is contemplated by the program now under discussion would provide desirable outdoor projects for unemployed men.

There is one minor point on which I disagree with Dr. Clapp as to details. He voices the need for an increase in the very costly studies of the forest and range influence problem. He contends that 4,000- to 17,000-acre watershed areas are the nearest approach to the large-scale studies needed and that in his judgment some 25 similar installations and 25 smaller ones are required. Although we still need more information on forest and range influences in order fully to supply the various details involved in demonstrating the great beneficial effects of forests and other vegetation in the control of erosion, I feel that we do not need immediately all of the costly installations suggested by Dr. Clapp. In order that those methods of control which are both effective and economical may be available for use, stress should be laid on the determination of such methods in connection with the launching of a control program. We do urgently need a mass of information on the details of reforestation, revegetation, and the management of forest and range lands on the headwaters and the upstream tributaries of our rivers now subject to devastating floods. In other words much of our research should be directed toward the development of effective and economical methods to be used in connection with flood control rather than toward the accumulation of data to convince ourselves that we have floods and that they must be controlled.

From this statement I do not mean to infer that we should fold our arms, sit back, and let

the silt-laden flood waters roll by. My suggestion is quite the reverse. I would advise proceeding immediately with the essential preliminary planning and such steps as are necessary to obtain the funds needed to inaugurate a fundamentally sound, well coordinated, conservative program of upstream management involving control and research along the lines indicated.

2. Leigh J. Young.

School of Forestry and Conservation, University of Michigan, Ann Arbor, Mich.

The data given in Dr. Clapp's paper, based upon exact measurements of run-off and erosion, occurring under widely varying conditions and in many localities, present unequivocal evidence of the important influence of a vegetative cover, especially a forest cover, upon water behavior. The results of these investigations are particularly valuable, because they represent what is happening under American conditions and may, therefore, be more convincing to our own people than the results of similar investigations that have been carried on in other countries. Judging from personal contacts with various classes of people, the laity is less in need of conviction on this subject than certain groups of the scientifically trained.

While such data show definitely the extent of the influence of a plant cover under given sets of conditions, to anyone who has worked much in the open and so has had opportunity to observe such matters they are not needed to prove the general thesis that such an influence exists. When quantities of soil appear suddenly in a stream previously clear, following the removal of the cover from part or all of its drainage area, it would appear that some relationship exists between the two occurrences. A similar conclusion is likely to be made when gullies occur on slopes only after they have been bared. Again there is the case of the small stream of year-round flow that becomes intermittent after the denuding of its catchment area. What we see with our own eyes is apt to be more impressive than any array of figures in cold type.

In 1916, the mountains of western North Carolina were deluged by a rain of unusual volume, which caused record-breaking floods in many streams, heavy erosion, and numerous landslides. These conditions were general throughout the region, but there were some notable exceptions. One of these occurred on one fork of a small stream in the vicinity of the town of Marion. The entire drainage area of this fork had been acquired by the town 8 years previously to protect its water supply. During that time, the area had been protected from fire, grazing had been excluded, and no cutting of timber had been permitted. The drainage area of the other fork had received no protection, and as a consequence, showed much poorer forest conditions, although there was a partial cover. The areas within the two watersheds were practically equal, and conditions of topography and original soil formation were alike. These two areas were examined on the same day, 2 weeks after the storm noted above, and showed some striking differences. At the high point following the storm, the unprotected fork had a flow 20 feet deep and 75 feet wide. Two weeks later, its entire flow was a ribbon about a quarter of an inch deep and 4 inches wide. The level of the protected fork had risen 18 inches as result of the storm, but at the time of examination had a flow sufficient to fill the town's water main and a surplus in addition. This surplus showed as a flow of 2 inches in depth over the full width (about 12 feet) of the dam that diverted the water into the main. Numerous landslides had occurred on the slopes of the unprotected area, and none on the protected one. The protected Asheville watershed at this same time showed an even more pronounced contrast with those of adjacent streams.

The experiences of other countries should give us added confidence in the proposition that the establishment and maintenance of a suitable

cover is an absolutely essential factor in adequate watershed protection. Among such experiences, that of the French in the Alps is particularly noteworthy, as it presents both sides of the picture. Valleys that were fertile and prosperous prior to the destruction of the forest on the slopes were devastated and depopulated by the action of torrents that followed that destruction. Later, many of these torrents have been subdued under the program of combining engineering works and reforestation at the headwaters, which grew out of the studies of the engineer, Surell, thus demonstrating the feasibility of such methods of control.

As Dr. Clapp has indicated, our own task is enormous. He has given us the fundamentals of the program that is needed. It is no longer a time for hair-splitting arguments but a time for all agencies having a part in such a program to get together and get into action.

CHAPTER VI

MANAGEMENT AND USE OF AGRICULTURAL LANDS INCLUDING FARM WOODS AND PASTURES

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U. S. DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

UPSTREAM engineering has been defined nowhere more succinctly than in the President's letter to the Secretary of Agriculture endorsing this conference. Upstream engineering seeks, the President said, "through forestry and land management, to keep water out of our streams, to control its action once in the streams, and generally to retard the journey of the raindrop to the sea."

Such a definition presents for the consideration of this conference a problem of intricate complexities and challenging possibilities. It encompasses all areas steep enough to shed rainfall, excluding not a single square foot nor even a single inch of land that slopes. It envisions the complete control of every drop of water that falls on the land, and its conservation to the ultimate limits of practicability. It presupposes an amalgamation of technical knowledge from many fields of scientific endeavor, inviting the engineer, the forester, and the agronomist; the climatologist, the economist, and the sociologist; and many others, to pool their efforts in a coordinated, carefully balanced plan for the efficient regulation and wise use of both land and water along the headwater drainages of our streams, even to the uppermost limits of the most diminutive streamlet and its enclosing watershed. Wise use of water upstream will not stop with control in fields and pastures and wood lots; such use calls for water conservation in ponds and reservoirs along numerous little waters, for purposes of flood control, recreation, replenishment of dissipated supplies of underground water, provision of water for stock on the farm and on the range, development of power for small groups of farmers and isolated communities, and the safeguarding and upbuilding of wildlife.

It is important, also, in analyzing the President's definition of the broad problem, to point out that it makes no allowance for the economic status of the land. Whether it be cropped, forested or pastured; whether it be publicly controlled, privately owned or tenanted; sloping land is all of one kind in the broad sense of its relation to water control. For the upstream engineer the problem remains simply that of "retarding the journey of the raindrop to the sea" regardless of the kind of land over which it flows. For him, the job is primarily physical, with the details of control differing according to the physical requirements of each parcel of land, however small it may be.

Nevertheless, the upstream engineer must temper his approach to the problem with careful consideration of those social and economic factors which influence the use of each kind of land, as well as those varied physical factors which make every parcel of sloping land a distinct problem in itself. Land management is more than the mere adjustment of land use to the purposes of conservation and water control. Involved, also, and even more difficult, are the adjustments which must be made simultaneously in light of economic necessity and the peculiarities of the social structure. Where

land is held in private ownership, such economic and social adjustments are necessarily most complex, it seems to me. Here the problem of land management is complicated by the rights of ownership, by individual farm economy, even by the personality of the individual landowner or operator. Under our system, the management of privately owned land is in a large sense the ultimate responsibility of the private landowner. Planning is likely to fall short of its purposes unless he is willing either to carry out the plans himself, help carry them out, or permit others to carry them out in his stead. Compulsion by State law or local regulation may be possible, in some instances necessary, to be sure, but voluntary individual initiative and cooperation growing out of a sense of personal responsibility is far more desirable, it appears to me.

Foremost in the mind of the landowner or operator, quite naturally, is the important matter of income. The management of land for flood control or conservation purposes may have beneficial effects both to him and to his neighbor, but such benefits may easily be overshadowed, in the practical sense, when his immediate financial return from the land is threatened.

On agricultural lands, therefore, and particularly on croplands and associated pastures and wood lots, the upstream engineer is confronted not alone with problems merely physical. His planning for the control of water on sloping fields and pastures must take into account much more than the physical adaptabilities of the land to certain uses. He must pattern his plan to fit as well into the economy peculiar to the region and to each particular farm or grazing area of that region, whether it consists of cropland or range land or forests.

We are concerned here, of course, principally, with the physical problems and techniques of agricultural land management and land use for upstream control of water and conservation of soil. But a discussion of those problems should proceed, it seems to me, only on the assumption that we are fully aware, at the outset, of those highly important economic and social considerations which must be taken into account.

It is the purpose of this paper to indicate the close relationship between mismanagement or maladjustments in the utilization of our agricultural lands, the progressive decline of the ground-water table, depletion of the soil, increasing hazards of floods, and silting; and to outline the techniques now available for regulating the behavior of rain water after it has fallen on the land. This will take us upstream not merely to a given county, township, subdrainage, farm, or grazing area but to a particular field, pasture, or wood lot on that farm or grazing unit, even to particular parts of such fields, pastures, and wood lots. It will require detailed consideration of soil characteristics, degrees of slope, existing cover and other factors which influence the susceptibility of land to accelerated run-off and soil erosion, in order to provide a basis for determining a land-use or land-protection program for each differing parcel of land that will articulate satisfactorily with the other distinctive areas that go to make up the entire farm or grazing unit. The thoroughness and integrity of this land inventory—this detailed survey of the physical complex of the farm, grazing unit, or drainage area—and the faithfulness and efficiency with which it is employed as the basis of planning will determine to a large extent the success of the treatment applied to a given tract of land or to a given drainage basin.

My thesis is that the proper treatment and management of land, soil husbandry if you please, is more instrumental than any other individual factor in determining the rate and volume of run-off and the consequent loss of soil from given agricultural areas. I believe sufficient information is now available to say with confidence that the frequency of moderate floods can be reduced and the crests of abnormal floods definitely lowered in many trunk streams by proper land treatment, which means efficient

land protection within the contributory watersheds. Indeed, it may be entirely within the realm of practical possibility to lower to a considerable extent the peak-flood crests that seem ever more frequently to be racing down our waterways. What actually can be done, of course, remains a matter for the future to determine, although, as will be pointed out, much has been accomplished already toward blazing the trail. Downstream engineering work must continue to carry a very large share of this responsibility; but it may reasonably expect assistance upstream where efficient adaptable measures of soil and water control are applied to the ultimate limits of our little waters.

Any program which will control soil erosion to an appreciable extent either on the average farm or over an entire watershed must reduce, in one way or another, the volume and rate of run-off water following rains and the thawing of snows. This means that a certain amount of water that otherwise would pass off as drainage will be conserved within the vast reservoir of the soil. The amount thus stored will depend, of course, upon local circumstances and the extent and efficiency of control work. In some of the drier parts of the country where the establishment of a cover of vegetation is essential to soil retention, water conservation is the primary objective of soil-conservation effort. Current investigations are indicating that water conservation is becoming of increasing importance and concern in many parts of the country, not only because of its relation to plant growth and to erosion control, but on account of the progressive decline of the ground-water table which has taken place during recent years.

The relationship between the conservation and control of water where it falls on the land and the conservation of land resources threatened by the erosive action of this water becomes quite apparent. Fundamentally, the problem of upstream engineering is a unified one, involving in essence the retention of rainfall in the soil and the simultaneous retention of valuable soil that otherwise would be carried away to reduce the channel capacities of our waterways, silt our lakes and artificial reservoirs, and make useless and unattractive a great number of natural and artificial bodies of water, valuable both from the utilitarian and recreational standpoint. The various other phases of complete upstream development—the conservation and protection of wildlife, the development of farm and community water supply and power resources, the establishment of recreational facilities, the diminution of drought severity through water conservation—these are more in the nature of ends which can be achieved only through the means of conserving basic soil and water resources. Our first concern, then, is with the fundamental problems of soil depletion and water wastage.

SERIOUSNESS OF EROSION

The productive agricultural lands of the United States are being seriously impaired and even destroyed on a vast scale. The plant nutrients and the very body of the soil itself are being removed from fields and overgrazed pastures and ranges at an ever-increasing rate under unwise methods of land usage, with the effect of impoverishing and destroying the uplands, and of covering fertile lower slopes and productive alluvial plains with sand, gravel, and poor subsoil material washed out of the hills. The products of erosion are filling stream channels, irrigation ditches, farm ponds, and costly reservoirs; accelerated run-off from soil-stripped, gully-riddled slopes is increasing the hazard of floods, and streams muddied with silt and colloidal clay are being deserted by valuable species of fish. Streams and springs are drying up as the water table sinks to progressively lower levels within watersheds deprived of their capacity to absorb adequate supplies of the rains that fall upon them. Centuries would be required to build back the soil swept from fields and overgrazed pastures of the Nation by this process that continues with every rain heavy

enough to cause water to run downhill, and with every gust of wind impinging against bare, sun-scorched fields.

More than 75 percent of the country consists of sloping land, all of which is potentially subject to erosion wherever used for clean-tilled crops or grazed. The average depth of the more productive topsoil on this sloping land is only about 7 or 8 inches. This shallow layer of indispensable natural resource, representing the farmer's principal capital, is being removed bodily at rates ranging generally from about 3 to 20, 60, or 75 years, depending on kind of soil, declivity of the land, rainfall, and type of agriculture.

A thriving agriculture is essential to national prosperity. When the rich humus-charged surface layer of soil is stripped from the land, it cannot be restored, even that which has been moved no farther than from the upper to the lower side of a field. Without this productive covering, agriculture generally cannot be prosperous, whether prices are up or down. No greater problem than the control of this process and the conservation of the water that causes it confronts the Nation today. The problem is national in character and scope. Its injurious effects touch directly or indirectly the interest of every citizen.

The land area of the United States is some 1,908 millions of acres. Of this, something like 610 million acres is classed as cropland. Of the latter it is estimated that about 50 million acres has been essentially ruined by erosion for further general use agriculturally, with still another 50 million acres damaged only to a slightly lesser degree. This is the equivalent of 1,250,000 farms of 80 acres each, an area nearly equal to the combined extent of Ohio, Illinois, Maryland, and North Carolina.

In addition, approximately 100 million acres still largely in cultivation has lost all or the greater part of the topsoil. This land is from 2 to 10 times less productive than was the virgin soil. It is more difficult and expensive to plow and sheds rain water more rapidly to increase the volume of floods, the rate of erosion, the sedimentation of reservoirs, and the shoaling of stream channels.

And, moreover, erosion is getting actively under way on still another 100 million acres. In short, half of the better cropland of the Nation has been affected by erosion in degrees varying from the stage of incipiency to complete destruction. Tens of thousands of farmers have become subsoil farmers which means something very close to bankrupt farming on bankrupt land. Moreover, the virtual ruin of the soil is essentially of a permanent character, jeopardizing the well-being of generations to follow.

The responsibility for coping effectively with this problem rests squarely upon the upstream engineer. It is essentially the crux of the situation with which he must concern himself. His approach in meeting this responsibility, I believe, is to devise and carry out a properly coordinated, complete, and adaptable soil-conservation and water-control program on all areas of land requiring protection or needing the water that goes to waste. Such a program, as I have previously indicated, calls for treatment of the land in accordance with the specific needs and adaptabilities of the many different kinds of land as well as in accordance with the interrelationships of these different areas that go to make up a farm. It insists upon conformance with the normal procedures of nature—the liberal use of vegetation in various adaptable practices, cultivation according to sound engineering principles, and the retirement of the steeper slopes from tillage. I am convinced on the basis of actual experience that any other method of approach will fall short of the objective. Delay in the application of such a coordinated land-use program simply means a more difficult and costly job ahead.

Farmers have been fighting erosion in some parts of the country for more than 75 years, notably in the southeastern Piedmont region; but generally they have failed. As a matter of

fact, the damage has outstripped all protective effort. Until recently it was a losing fight because of two major shortcomings: Ignorance with respect to the seriousness of the problem, and the physical impossibility of combating it in any effective way by a piecemeal or single-project method, in which only one implement, such as hillside ditching or hillside terracing, is employed. On gently sloping land this single-track method of combat has been effective, but on a very large area of steeply sloping, highly erosive soil the practice probably has done as much harm as good.

We are here concerned, of course, only with accelerated erosion caused by man's intervention in balanced natural environments. We are not concerned with the exceedingly slow process of normal or geological erosion. It should be perfectly understood that accelerated erosion is the product of excessive run-off caused by the reduction of the infiltration and absorption capacities of sloping land which follows the removal of the stabilizing cover of vegetation and subsequent careless cultivation and grazing of the land since white man's occupation of the continent.

Absorption, percolation, run-off, and erosion are interdependent processes, and for all practical purposes may be considered as a combination four-phase physical agency of land decline and water wastage. These processes—rather, this composite agency is profoundly influenced by slope, soil, climate, density of cover, and the use made of the land. When the normal vegetative cover is removed the soil is laid bare to the full destroying effects of violently rushing rain water and sweeping wind. The process of plowing vitiates or destroys the effective permeability of the virgin soil by disrupting its normal granular or loamlike structure, and closes the hidden conduits made by earthworms, insects, and plant roots. With further cultivation the humus content—the life-giving, spongelike binding material—is dissipated by processes of decomposition and oxidation. In this way, man within a few brief years emasculates or effaces what nature has taken centuries, even thousands of years, to build.

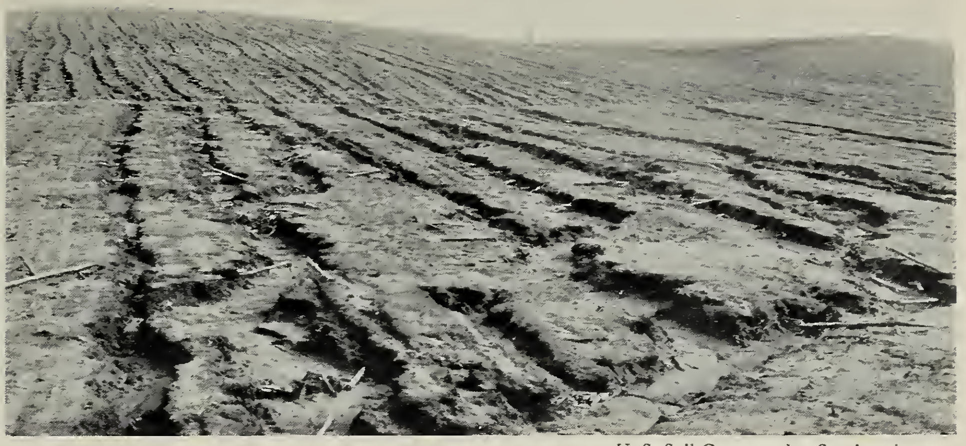
The average American has no particular love for the land and little understanding of it. The explanation is fairly simple. Colonists pouring in from great reservoirs of population in Europe began a westward march across America under conditions that led them to believe the continent was endowed with limitless and inexhaustible supplies of land. Now that our frontiers have disappeared in the Pacific, and are reappearing in the East and West, the aftermath of the "conquest of America" is apparent. Vast stretches of forest are gone, the buffalo have been killed, some species of game birds have been exterminated, and we find hundreds of millions of erosion-made gullies and tens of millions of acres of erosion-exposed clay subsoil where there was not a single gully of this kind nor one acre of man-induced freshly exposed subsoil when the country was taken over by the white man.

The extent of this damage by erosion is indicative of more than a critical land problem. It serves as well to indicate the enormousness of the upstream water-control problem. Most of the eroded land in this country was damaged by run-off waters that rushed into streams, heavily silt-laden, from unwisely treated fields, pastures, and ranges. The wastage is continuing at an accelerated rate. Much land, also, has been damaged by wind erosion, a process that functions much after the manner of water erosion, and calls for similar control measures, involving the conservation of every possible drop of rain in the soil for stimulation of protective plant growth.

NEED FOR ADDITIONAL INFORMATION

Looking then, at soil and water conservation as a single interdependent problem, it is evident that we are largely concerned with cause and effect on the one hand and with prevention or cure on the other. This being the case, a prerequisite to action on the land is the develop-

FIGURE 41.—Severe sheet erosion of a corn field cultivated up and down the slope.



U. S. Soil Conservation Service photo.

U. S. Soil Conservation Service photo.

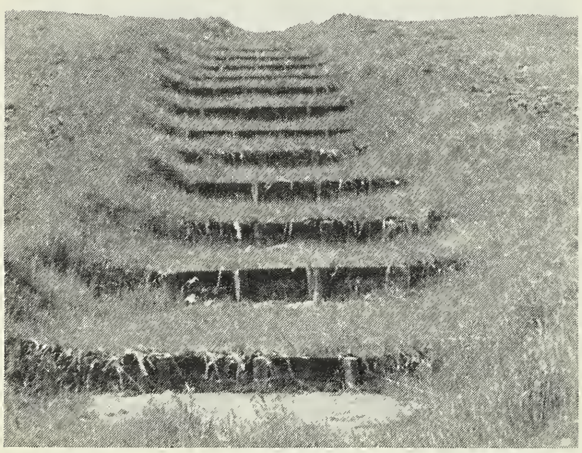
FIGURE 42.—The orchard land on the right lost about 200 tons of soil per acre during a single rain; the adjoining land with vegetative cover lost none.

FIGURE 43.—Destruction by erosion of the field in the background will proceed at an accelerating rate if proper control methods are not employed.

U. S. Soil Conservation Service photo.

U. S. Soil Conservation Service photo.

FIGURE 44.—Terracing and contour listing.



U. S. Soil Conservation Service photo.

FIGURE 45.—A controlled gully.

U. S. Soil Conservation Service photo.

FIGURE 46.—Simple but effective check dams.

U. S. Soil Conservation Service photo.

FIGURE 47.—Strip cropping in Ohio.

ment of a sound and comprehensive framework of research sufficiently broad to encompass all aspects of the work, including the essential phases of soil science and engineering, hydrology, climatology, aerology, ecology, agronomy, forestry, geomorphology, biology, and plant physiology, as well as agricultural economics and other allied fields of study. In view of the character and number of complex, closely related fields involved, it is obvious that nothing short of a broad, basic plan of research can possibly serve as a safe and adequate foundation for developing and perfecting the more permanent phases of an action program.

Loss of soil and water from our agricultural lands has been recognized as a serious problem for several decades. Only during the last 3 or 4 years, however, have we undertaken in any large degree constructive and sustained action. Consequently, there is an acute need for specific information and fundamental data relating to the mechanics of soil-erosion processes and methods of control and prevention. Aside from the early work on run-off and wash-off started by the Missouri and Texas Agricultural Experiment Stations and the considerable amount of study that had been given the broad-base terrace by the Bureau of Agricultural Engineering and a number of State experiment stations, comparatively little systematic research had been carried out in this important field up to 1928. In that year, a series of erosion experiment stations were initiated jointly by the Bureau of Agricultural Engineering and the Bureau of Chemistry and Soils in cooperation with the State experiment stations. At these stations, for the first time, a broad-scale effort was inaugurated to ascertain the physical nature of erosion processes and the kind of prevention and cure required for particular land and watershed conditions. This phase of agricultural research, being so new, required, for the most part, that new techniques be developed and a new methodology evolved. For these and other reasons progress has been slow, especially under conditions where impatience is fostered by a strong desire to move on with the practical job of conservation throughout the Nation.

Much, therefore, remains to be done in this field; we do not, by any means, know all that we should know about fundamental principles involved with either water or wind erosion, nor have we acquired all the information needed in the way of practical measures of control and prevention. Our investigations thus far have shown, for example, that sheets of water flowing across certain peculiar soils involve loading and unloading behaviors with respect to silt, as well as peculiarities of abrasive plantation and incision, that are almost entirely outside present understanding. For example, we know little about the hydraulic principles under which, with identical conditions of soil, slope, cover, and rainfall, as much soil material is removed from an area of narrow width, on certain types of land, as from an area of much greater width. As a matter of fact, very little attention has been devoted to this abstruse phase of hydraulics, as well as numerous other processes in this field, which involves, perhaps, as many variables and complexities as any branch of dynamics. We have not even initiated investigations in relation to differential erosion, and we have scarcely touched the field of subsoil tillage, especially in its adaptation to particular subsurface structures and consistencies as a practical means of stimulating water conservation by infiltration.

Seemingly, we have acquired far too little information with respect to the amount of water that falls on the land. The astounding peak of the disastrous 1935 flood in the Republican River is an illustration in point. That peak climbed far above any curves likely to have been projected on the basis of rain-gage records within the watershed of that stream, or of neighboring streams. Even the precipitation readings for the rain that brought on the disaster do not account for the prodigious volume of water that charged down the valley; somewhere between the established gages the rainfall must have

attained intensities wholly out of line with any actual measurement.

In this connection, attention might pertinently be called to Thornthwaite's studies now in progress in Oklahoma, in cooperation with the Weather Bureau, in relation to the characteristics of growth or development of rainstorms. Time does not permit presentation of the details, but a glance at the exhibit in this hall shows that rainstorms, some rainstorms at any rate, do not expand and recede with regularity of intensity over any considerable area. [1]

The paucity of exact information regarding the highly important relation of ground-water depletion to land use is astounding. Most of the information on the subject is of a decidedly fragmentary and unsatisfactory nature, much of it dependent on observation only.

These references to a few of the things about which so little is known, out of the vast unexplored field, by no means imply that no worthwhile knowledge has been acquired from research or from observation and experience, respecting soil and water conservation on the land. As a matter of fact, we have acquired a tremendous amount of very helpful factual information from studies of erosion processes and precise measurements of water and soil losses and of water infiltration under varying conditions of soil, slope, cultural treatment, and rainfall intensity. In addition, recent experience with actual erosion-control and water-conservation projects on a large scale has provided a considerable amount of the most pertinent information, especially with respect to the efficiency of practical methods of control and prevention. Out of our upstream experiences, through the carrying out of a vast amount of protective work on the lands of some 35,000 farmers, as well as on many millions of acres of public lands, and through the construction of 1,397,000 check dams and 178,000 permanent dams in gullies and small drainages, under widely varying conditions of soil erosivity, channel gradient, and climate, we have developed a variety of adaptable farm measures, structures, and installation methods which have proved greatly superior to those employed 2 or 3 years ago on the basis of the best information then available. We have been forced to develop new techniques for building channelways needed for safe conduct to lower slopes of the excess water flowing from field terraces. We have been forced also to develop new techniques for safeguarding those vulnerable points where excess water debouches from fields into roadside ditches or from fields and pastures onto unprotected eroding slopes. We have found it necessary as well to develop new methods for economic utilization of waste water in connection with flood irrigation, in the establishment of meadow waterways and diversion channels, and even in tearing down troublesome escarpments and angular land forms sculptured by unrestrained erosion. In the regions of severe wind erosion we have developed an entirely new method for leveling dunes by use of the wind that builds them.

It is impossible here to discuss in any adequate way the details of the present Nation-wide program of conservation work on the land, involving more than 7 million acres of privately owned land and 40 million acres of public land; but it may be helpful to present a few of the results obtained, together with some of the more basic procedures followed. These results should prove of immediate practical importance in planning for upstream engineering. It is well to understand that references to the use of vegetation in erosion control and water conservation are not to be construed as implying that such methods have to do merely with agronomic or forestry techniques, inasmuch as they very definitely involve engineering principles as well, at least in many instances. For example, engineering techniques are inextricably tied in with methods involving effective establishment of grass dams, correct placement of wattle, determination of the right width and location

[1] This is more fully discussed by Thornthwaite on p. 155.

for water-impeding strip crops and location of the most advantageous points of reinforcement in stabilizing earthen dams and hillside terraces with grass, shrubs, and trees.

THE USE OF VEGETATION IN EROSION CONTROL

Data on soil and water losses obtained from experimental areas, as well as observations from general field activities, have shown the tremendous effectiveness of close-growing vegetation in slowing down run-off and stabilizing soil against both wind and water. This has been true with a consistency that would be monotonous were not the information provided by these studies and demonstrations of the greatest importance in the interest of water and soil-control operations. The general trend can well be illustrated by citation of some of the results.

Soil and water losses are greatest under conditions where the land is bare of vegetation; next in magnitude are the losses from areas devoted to the cultivated or clean-tilled crops, such as cotton, corn, tobacco, potatoes; and least in magnitude are the losses from ground covered with forest, grass, clover, alfalfa, shrubs etc. Summing up the average comparative losses from 13 widely separated important agricultural soils representative of or closely related to the principal types of farm land within a predominantly agricultural area of approximately 250 million acres (table 8), it has been found, over a 2- to 6-year period of measurements made in accordance with the most exact methods known to science, that the loss of water from fields devoted to clean-tilled crops has been approximately 7 times greater than the loss from fields protected with close-growing crops, such as grass, legumes and woods; and, further, that the loss of soil has been 174 times as much as from protected areas.

Measurements of run-off and erosion made within the watershed of one of the upper tributaries of the Susquehanna River, near Ithaca, N. Y., during the period from March 1 to 19, 1936, just preceding the disastrous flood in the Susquehanna Basin, revealed the following results:

The losses of water as immediate run-off from two potato fields were 75 and 82 percent of the

TABLE 8.—*Comparison of water and soil losses*

Under (*a*) cultivation and (*b*) a protective cover. From 13 widely separated important agricultural soils representative of the principal types of farm land within an area of approximately 250,000,000 acres]

Station	Soil	Annual rainfall	Slope	Cultivated			Protected		
				Crop	Water loss	Soil loss	Cover	Water loss	Soil loss
		Inches	*Percent*		*Percent precipitation*	*Tons per acre*		*Percent precipitation*	*Tons per acre*
Statesville, N. C.	Cecil sandy clay loam	45.22	10	Cotton	10.2	22.6	Virgin woods	0.12	0.002
	Nacogdoches fine sandy loam	43.19	10	do	16.8	6.5	Grass	.77	.006
Tyler, Tex.	Kirvin fine sandy loam	40.52	8.75	do	19.5	19.1	do	.70	.083
Columbia, Mo.[1]	Shelby loam	40.37	3.7	Corn	29.4	19.7	do	12.0	.3
Bethany, Mo.	Shelby silt loam	34.79	8	do	28.3	68.8	Alfalfa	7.5	.25
Zanesville, Ohio	Muskingum silt loam	34.51	12	do	35.2	59.6	Grass	5.8	.034
La Crosse, Wis.	Clinton silt loam	34.12	16	do	20.6	88.3	do	1.7	.019
Guthrie, Okla.	Vernon fine sandy loam	33.12	7.7	Cotton	14.3	24.3	do	1.2	.032
Temple, Tex.	Houston black clay	31.34	3.75	Corn	13.7	20.9	do	.043	.032
Clarinda, Iowa	Marshall silt loam	26.82	9.6	do	8.6	18.8	Alfalfa	.83	.022
Pullman, Wash.	Palouse silt loam	21.74	30	Hard fallow	24.9	27.6	Grass	3.2	1.4
Hays, Kans.	Colby silty clay loam	20.36	5	Kafir	16.2	11.8	do	.33	.029
Spur, Tex.[2]	Miles clay loam	18.06	2	Cotton	10.4	5.1	do	.30	.048
Average		32.63			19.5	30.2		2.9	.17

[1] From Bul. 177, Missouri Agri. Expt. Station.
[2] Results for 1927 and 1928 from Bul. 411, Texas Agr. Expt. Station.

Results show approximately 6.8 times as much water loss from clean-tilled crops, and 174 times as much soil loss, as from protective cover ,such as grass, legumes, and woods.

total precipitation, respectively, on land having a slope of 14 percent; and there was a moderate loss of soil by erosion. Of 9.47 inches of rain and snow, 7.1 and 7.85 inches, respectively, ran off during this critical period, but there was no measurable erosion. In contrast, the corresponding loss of water from neighboring forested areas having a 27-percent slope averaged less than 0.5 percent of the total precipitation, including both the rain and the snow that had accumulated before the rain. It is interesting that the ground beneath the cover of forest litter was not frozen, whereas that in the potato fields was frozen. Still more surprising was the fact that from neighboring grassland, with a slope of 20 percent, the run-off was less than 0.1 percent of the total precipitation.

GRASS HIGHLY EFFECTIVE IN CONTROL OF WATER

At the soil and water conservation experiment station near Zanesville, Ohio, on a 12-percent slope of the principal type of farm soil in the unglaciated northern Appalachian region (Muskingum silt loam), measurements over a 2-year period, under a rainfall averaging 34.5 inches annually, have shown that 42.5 percent of the total rain and snow falling on bare ground was lost as run-off. Where the land was planted continuously to corn, 35.2 percent of the precipitation was lost; but nearby on the same kind of land handled under a rotation of corn, wheat, and grass, the water loss amounted to only 18.4 percent of the total fall of rain and snow. A bluegrass area of exactly the same kind of land lost only 4.5 percent of the precipitation.

The corresponding soil losses were: From land bare of vegetation (fallow), 54.7 tons per acre annually; and from land devoted continuously to corn, 59.6 tons per acre annually. Where a crop rotation was practiced, however, the annual soil loss amounted to only 8 tons an acre. From the same kind of land covered with bluegrass the annual rate of soil removal by erosion dropped to the almost insignificant amount of 100 pounds an acre, or 1,192 times less than the loss from cornland of the same slope and the same kind of soil, receiving the same rainfall.

At these rates, it would require only 21 years to remove 7 inches of topsoil (which is about the average depth of the topsoil in the region) from the bare land, 19 years to remove the same depth of soil from the land planted continuously to corn, 145 years to wash off an equivalent depth of soil from land under crop rotation, and 23,200 years to strip off as much topsoil from the field in bluegrass.

At the LaCrosse, Wis., soil and water conservation experiment station, measurements over a 3-year period have shown that 20.6 percent of all the rain and snow falling on land in continuous corn was lost as run-off. Under a 3-year rotation of corn, barley, and clover, the same kind of land lost 12.1 percent of the total precipitation; but where covered continuously with grass, only 1.7 percent of the water was lost as immediate run-off. These test fields were on a 16-percent slope and the average annual rainfall was 34.12 inches. The soil (Clinton silt loam) was typical of the principal farm land in an area of some 12 million acres, comprising the unglaciated sections of southwestern Wisconsin and adjacent Minnesota, Iowa, and Illinois.

The corresponding losses from the different types of land were as follows: 88.3 tons an acre annually from cornland, 25.3 tons from the rotated area, and only 38 pounds a year from grassland, or 4,647 times less than the loss from cornland.

On the basis of these measurements, only 11 years would be required, under continuous corn, to remove 7 inches of this Wisconsin topsoil, which is about the average depth of the surface soil in the locality. To wash away an equivalent depth of soil from the field in rotation would require 40 years and from grass 53,000 years. The exceedingly slow rate of erosion taking

place under grass (normal or geological erosion) probably means that the soil is stabilized; that is to say, soil under such a cover probably builds from beneath as fast as it is removed from the surface.

In view of the small loss of rain water from land having a good vegetative cover, together with the greatly reduced water losses where cropping practices are supported by protective strips of vegetation and by other adaptable control measures, such as terracing and contour tillage, it seems logical to expect the farmer who adopts conservation-farming practices to contribute substantially to the prevention and control of floods.

LAND-USE CHANGES AND REDUCED FLOODS

Actual results from the application of conservation practices to the land are perhaps even more emphatic in illustrating the effects of land management for soil and water conservation.

Within the watershed of Big Creek in north-central Missouri and adjacent Iowa, comprising approximately 155,000 acres, the erosion problem has almost been solved in about 3 years of conservation work. As an incidental result, recent floods along that stream have been greatly reduced in severity as compared with its own previous floods, as well as with concurrent floods along neighboring streams draining the same type of country.

Of 1,042 farms within the drainage basin of Big Creek, a cooperative erosion-control and water-conservation program is well advanced on 833 farms, and considerable work has been carried out independently on most of the other farms. Surveys of the general region reveal that, depending on the particular locality, severe erosion has affected from 8 to 36 percent of the land, moderate erosion 10 percent, slight erosion from 16 to 26 percent, and that from 35 to 43 percent of the land has been affected seriously by gullying. The most extensive and important type of soil, the Shelby loam, has been damaged by erosion to various degrees over 63 to 75 percent of its area.

Census figures point to some of the primary causes of this condition of rapid land decline: Approximately 50 percent of the Shelby loam is cropped and 45 percent is in pasture, frequently overgrazed. Only about 1 percent is in timber. Of the cropped land, 45 percent is devoted to corn, a crop very conducive to erosion, especially under conditions of cultivation that have prevailed here in the past, such as plowing up and down the slopes and too frequent planting of corn after corn.

Some of the more important land-use changes effected by the soil-conservation program applied to this project are as follows:

Highly erosive land taken out of cultivation acres..	18,177
Increased area devoted to erosion-resistant crops acres..	19,528
Decreased area of clean-tilled crops.....do....	17,863
Highly erosive cultivated land and overgrazed pasture returned to forest...........acres..	1,284
Cultivated land strip cropped.........do....	6,393
Cultivated land contour tilled.........do....	12,960
Cultivated land terraced..............do....	4,291
Gully planting on...................do....	3,925
Temporary dams built to control eroding gullies.	4,139
Permanent dams built for erosion control, replenishment of underground water supply and for stock use.............................	575
Soil-building, water-conserving rotations introduced on practically all sloping cultivated land.	

In June 1935, Council Creek, near Stillwater, in the Red Plains of Oklahoma, went high over its banks, inflicting severe damage to crops. The neighboring stream, West Fork of Brush Creek, which drains the same kind of land, used for the same type of agriculture, failed to top its banks, even though the rainfall was considerably heavier than that recorded over the watershed of Council Creek. Previously, the West Fork of Brush Creek had, under similar circumstances, flooded in unison with its close neighbor.

Erosion had been severe, and of much the same degree, within the two watersheds. How-

ever, practically nothing in the way of effective erosion-control and water-conservation work had been done within the watershed of Council Creek, while 50 percent of Brush Creek Basin had been covered by a complete conservation program.

REVIVAL OF STREAMS AND SPRINGS AS THE RESULT OF SOIL AND WATER CONSERVATION WORK

An example from the Pacific Northwest graphically illustrates the valuable effects of soil and water conservation practices when applied to any considerable proportion within a watershed.

For 3 years the Soil Conservation Service has operated here an erosion-control demonstration project comprising 100,000 acres, included principally within the watershed of the South Fork of Palouse River, in Washington State. Farmers owning 53,000 acres of this land are cooperating actively in the program of conservation. Still other farmers have carried out, independently, various phases of the program.

Here is what upstream engineering or conservation farming, as you choose to call it, has meant in this watershed:

More than 4 billion gallons of water (147,280 acre-inches) that would otherwise have flowed off immediately have been stored in the soil where it has been useful not only in stimulation of better plant growth but also in replenishment of the underground-water supply so valuable to stabilized agriculture. Instead of flowing rapidly and ruinously off the land, this large volume of rain water has been saved, through practices favoring increased infiltration, for the use of farmers as an incident to the work of stabilizing the eroding slopes of some of the most productive wheat land on the face of the earth.

Prior to the introduction of soil and water conservation practices on the South Palouse watershed, the river channel had become normally dry or practically dry except during the season of melting snow and heavy rainfall; and at such times, the stream became a raging, uncontrollable torrent pouring over the banks and flooding the business section of Pullman, Wash., and ravaging farm lands at least once each year, or sometimes more often. Since 1934, however, the stream has at no time overflowed its banks.

About 35 years ago the South Fork of Palouse River was a constantly flowing stream, and fishermen at Pullman caught trout from it regularly. Gradually, with the advance of agriculture, and especially the practice of summer fallowing, so conducive to erosion and accelerated run-off, the flow during the dry season became less and less. The transition took place so slowly that scarcely anyone noticed the change, until finally, during late summer, it dried up almost completely, with only occasional stagnant pools or wet places.

Farmers in the watershed assert that a large majority of the springs that formerly ran throughout summer have entirely dried up, with not more than 10 to 20 percent now remaining active.

The soil and water conservation practices applied to the land through the Palouse River watershed project have markedly remedied the situation, both with respect to revival of springs and flow of water in the streams.

The history of a typical spring in the South Palouse Basin is as follows: It flowed permanently until the continued growing of wheat, with alternate summer fallow, resulted in its gradually drying up. Sixteen years ago, only a seepage spot remained. Then, under the recent conservation program, the entire up-slope area from the spring was seeded to sweet clover, which was grown for 2 years and plowed under. Thereafter the spring resumed its flow and gained in water delivery until now the yield is said to equal that of several decades ago.

During the past 2 years South Palouse has had a substantial flow of water even thoughout the driest part of summer, and this year, in the face of the lowest precipitation in 43 years of rainfall records, the flow has continued steadily. In Pullman, once again the boys are catching trout,

some of them measuring up to 15 inches. The fish have travelled via the revived stream either from a permanently flowing channel in the North Fork, 50 miles distant, or from the permanently flowing portion of the Palouse 60 miles downstream. Prior to 1935 and 1936, however, no one remembers a trout having been caught in the South Fork for more than two decades.

The widespread use of adaptable conservation farming practices within the immediate watershed provides the only reasonable answer to these sharply defined and beneficial changes in soil and water conditions within the Palouse project area. These practices consist chiefly of the planting of grass, sweetclover, alfalfa and mixtures of these plants on the steeper, more erosive slopes, the preservation of crop stubbles, the practice of rough tillage and the building of numerous check dams in the smaller gullies and permanent dams in the larger ones. As a single measure of control, approximately 20,000 acres of highly erosive soil, formerly unprotected, and rapidly wasting away have been stabilized with grass and other close-growing crops in such manner as to favor largely increased rainfall absorption over the system of alternate clean-tilled summer fallow, as shown by actual measurement.

EFFECT OF LAND USE ON FLOODS

Some specialists have scoffed at the importance of watershed improvement in relation to flood control. They question the statement that either cultivation or denudation of land contributes in any considerable degree to floods. They hurry to point out that this country experienced floods long before the ax and plow were known to America, and that when DeSoto first saw the Mississippi it was in flood.

I agree in part. The flood record is plain. We have always had floods, and until some cataclysmic change upsets our existing regime of climate we shall always have them. Every strip of alluvium along every stream throughout the world is the product of deposition from overflow water; alluvial soil is formed in that way, and only in that way. The whole mass of material forming the alluvial plain of the Mississippi was deposited and spread out by floodwaters through a slow process of land building—sedimentation—which probably had its beginning millions of years before DeSoto discovered the river.

The meanderings of the Mississippi through its self-built plain since remotely ancient time are recorded in the geological characteristics of this alluvial material. The records show beyond any question that there have always been floods along that mighty stream. But the records show considerably more than that.

Overlying the primary bottom lands of numerous streams throughout the United States—the material laid down by timeless floods—is a different kind of alluvium. It consists of sediments spread out by floodwaters since the beginning of our agriculture—since the ax and the plow were introduced to America. These sediments reveal unmistakable proof that, generally, they were spread over the flood plains by waters much more violent than those which laid down the older material beneath.

There is marked difference between the old and the new deposits. The finer texture and more uniform composition of the preagricultural sediments show that they were developed under conditions of moderate overflow. This is not true of the newer deposits. In many instances, the depth of this newly laid material is greater than the entire depth of the deposits underneath, even though the former were accumulated in many places within 25 to 75 years, whereas the buried material required long periods—in some instances probably tens of thousands of years—for its deposition. Generally, the deposits of the agricultural stage are not only coarser in texture, but far more diverse with respect to composition and color of the successive layers through the profile. The line of separation between the two types of alluvium—the preagricultural and the agricultural—is so sharp that it is usually possible to

photograph it without difficulty (see fig. 48).

Today, the Bureau of Chemistry and Soils of the Department of Agriculture is mapping a number of new alluvial soils entirely different in character from those of pioneer time. We have the history of these soils and know definitely that they have been formed since the agricultural occupation of the country. There is also ample proof that these later deposits were laid down by more violently flowing waters than those of former times.

CONSERVATION OF WATER BY CONTOUR TILLAGE AND TERRACING

At the Spur, Tex., and Goodwill, Okla., stations, the average content of soil moisture was increased approximately 25 percent by contour tillage and level terracing. At Goodwill, the additional moisture conserved in this way resulted in seven better-than-average yields of wheat during a 10-year period, whereas without contour cultivation only four crops of better-than-average yield were produced over the same period. The prevention of run-off through contour cultivation increased the chances for a successful crop by approximately 75 percent, with a corresponding increase in yield of approximately 35 percent.

In the Southern Plains region of Texas, Colorado, New Mexico, Kansas, and Oklahoma, 2,474,000 acres were listed on the contour early in 1936, with the result that practically all the spring rain was held in the fields. One inch of moisture was stored in the subsoil as the result of this contouring. Tests following these May rains showed that the moisture penetration was more than a foot deeper on contour listed land (about twice as deep) than on untreated land of the same character receiving the same rainfall. This stored moisture resulted in far better growth of sorghum than on the untreated land.

FLOOD IRRIGATION

At Mexican Springs, N. Mex., in connection with the soil and water conservation work on the Navajo Reservation, an earthen dam was thrown across an actively eroding arroyo to divert the water out over adjacent flats, formerly essentially bare of vegetation because of overgrazing. The result in 1935 was a splendid growth of grass over some 300 acres and a production of corn yielding up to 60 bushels an acre on an additional 200 acres. This simple, low-cost method of utilizing water that formerly ran to waste accomplished four distinctly useful things: (1) It provided protection for the rich lowland soil that was being cut away by the expanding gully, (2) it held back silt that otherwise would have been discharged into Boulder Reservoir, (3) it provided food for the needy Navajos and feed for their livestock, and (4) in providing additional human food and stock feed it afforded a measure of relief to the overgrazed highlands upstream.

Throughout much of the western range country and over most of the Great Plains there are literally thousands of areas favorably located for beneficial use of waters now going utterly to waste. Low-cost dams, diversion ditches, and contouring can be used effectively for this purpose on numerous areas of 10, 20, a hundred, or several hundred acres.

CONSERVATION OF WATER WITH SMALL DAMS

Opportunities for economic installation of small permanent dams for stock water, for raising fish and waterfowl, for small power purposes, for building up underground-water levels lowered by gully incisions and other causes, and, in the drier regions, for small-scale irrigation, are vast indeed.

As an illustration of the benefits to be derived from such work, the instance of a small-rubble masonry dam, 10 miles east of Bismarck, N. Dak., completed by the Soil Conservation Service in 1934, is worthy of note. This dam, installed in a small waterway on the farm of Irvin Reid, was only 6 feet high, yet it held and backed the water nearly 3 miles upstream. From it Reid,

the owner of a 320-acre farm, this year pumped enough water to irrigate 42 acres. In the midst of wholesale desiccation of the regional vegetation by drought, three cuttings of alfalfa hay were produced this year—enough to feed throughout winter the 50 head of cattle on the farm, including 10 milch cows. This small irrigated area was the basis of the sale of sugar corn, carrots, tomatoes, cream, eggs, and chickens, with potatoes and some beef cattle yet to be sold—enough to pay taxes and provide for a satisfactory living. The operator will extend his irrigation operations to 100 acres, and a neighboring farmer is planning to irrigate 60 acres of his land—all with water made available with this inexpensive small dam, which now has been in operation for 3 years.

To date, 300 somewhat similar permanent dams, some considerably larger, have been completed in North Dakota alone, chiefly with C. C. C. and W. P. A. labor, under the direction of the Soil Conservation Service, and the water stored therein—water that otherwise would have been wasted—is being used for stock by numerous farmers. Others afford fire protection to small range towns, and still others are being used for recreational purposes. Wild ducks are now frequenting many of these artificial lakes.

Of the total water storages built in North Dakota alone, 140 can be drawn upon to irrigate from 20 to more than 200 acres of land each. In addition, the water supply of four municipalities has been adequately safeguarded as the result of increased seepage from these storages into their supplies, and two others will take water from the reservoirs to supplement the dwindling town supply.

SILTATION

The importance of the control of stream-channel and reservoir sedimentation as a vital factor in the maintenance of open channelways and reservoir storage capacity has been specially investigated by the Section of Hydrodynamic Studies, Soil Conservation Service, during the past 2 years (Tech. Bul. 24). Detailed capacity surveys have been made of some 35 reservoirs, mostly in the southern half of the United States, to determine the actual volumes of silt that have accumulated over known periods. Reconnaissance examinations have been made of nearly 500 other reservoirs throughout the same regions. Although these studies have dealt, for the most part, with reservoirs of larger size, the results, with respect to rates of silt production from watershed areas under characteristic present-day erosion, are directly applicable to the small reservoir problem. This is particularly true of investigations made in the Southeast, where significant contrasts were found in rates of reservoir silting in the extensively cultivated rolling Piedmont region, on the one hand, and in the predominantly forested watersheds of the adjacent Blue Ridge province, on the other.

In the Piedmont section literally scores of small reservoirs with dams 10 to 30 feet high and many of major capacity only a few decades old are completely filled, except for a normal stream channel through the silted area of the original pond. Thirteen major reservoirs in the Carolinas and Georgia have been silted to the top of the dam within an average period of less than 30 years. Abandoned power plants and dismantled machinery are undeniable reminders of excessive sedimentation in these storage reservoirs. At the same time in the nearby reservoirs of forested mountain watersheds no silt deposits of any practical importance were found.

Typical of the smaller reservoirs that have succumbed to sedimentation are those of Deep River, downstream from the municipal reservoir at High Point, N. C.; Gilreath's Mill on a tributary of the South Fork of Tiger River, S. C.; Jenkins' Mill on Glade Creek, northeast of Gainesville, Ga.; and Barrett Mill on East Sandy Creek, Athens, Ga.

The costly effects of erosion, then, do not end with damage to the land. Soil washed from sloping areas and pastures—not less than 3 billion tons of it a year—is either poured into

streams, harbors, reservoirs, lakes, and the oceans, or is deposited along lower slopes and over flood plains, often doing great damage to the land. Probably two-thirds of the vast load comes to rest in stream channels and power- and water-supply developments, or is stranded elsewhere on its interrupted journey to tidewater. Scant attention has been given the matter of sedimentation. But recent studies indicate quite clearly that we cannot economically maintain adequate open-stream channels or have permanent water-storage systems in many of our valleys until we have curbed erosion along the headwaters of contributory streams.

WATER AND SOIL LOSSES FROM RAINS OF HIGH INTENSITY

Since the losses of water and soil previously cited relate to averages, it is important to point out that the effective protective measures being emphasized in the coordinated program of conservation, especially vegetative measures, are proving highly efficient, also, under the impact of rains of cloudburst intensity. For instance, approximately 35 percent of the record rain at the Tyler, Tex., soil and water conservation experiment station, in May 1936, was lost as run-off where the ground was bare, while only four-tenths of 1 percent was lost from the same kind of land covered with grass (table 9). This rain attained an intensity of approximately 13 inches per hour. At Hays, Kans., in a 25-year record rain on August 1, 1932, attaining an intensity of more than 4 inches an hour, bare ground lost 59 percent of the total precipitation as immediate run-off, as against only a little more than 1 percent lost from native sod.

It is interesting to note that under a wide range of soil, slope, cultural, and climatic conditions a good cover of grass or other dense vegetation greatly reduces the run-off of rains of all intensities (table 10) in a vast majority of the thousands of measurements that have been made of individual rains throughout the country.

RELATION OF RUN-OFF AND EROSION TO SIZE OF AREA

Much of the data which I have cited relates to run-off rates and erosion from small areas of uniform soil and slope, and, therefore, cannot be assumed to represent precisely what takes place under similar conditions of rainfall within entire watersheds, or even on large areas of land of the same or much the same character. We have much to learn as to how applicable these results are to flood flows in trunk streams. Certainly our information to date commands us to investigate further.

TABLE 9.—*Water and soil losses from rains of record intensity at 5 soil and water conservation experiment stations*

Frequency	Station	Date of rain	Rainfall		Intensity		Cover	Slope	Run-off	Soil loss
			Amount	Duration	Actual rate	Maximum rate				
			Inches	*Hours*		*Inches per hour*		*Percent*	*Percent precipitation*	*Tons per acre*
100 years	Tyler, Tex. (Kirvin fine sandy loam).	May 8, 10, 1936	4.7 5.13	9.17	1.08 inches in 5 minutes.	12.96	Bare Grass Forest	8.8 16.5 12.5	34.92 .35 .86	44.49 None 0.10
25 years	Guthrie, Okla. (Vernon fine sandy loam).	May 31, 1932	3.04 3.04 2.81	10	1.5 inches in 20 minutes.	4.5	Bare Grass Forest	7.7 7.7 5.2	53.06 2.30 .26	2.59 .015 .005
25 years	Hays, Kans. (Colby silt loam).	Aug. 1, 1932	1.50	.66	1.4 inches in 20 minutes.	4.2	Bare Grass	5.0 5.0	59.2 1.2	4.07 .01
20 years	Bethany, Mo. (Shelby silt loam).	Apr. 3, 1934	3.75	9.25	2.85 inches in 90 minutes.	1.90	Bare Grass	8.0 8.0	52.7 39.2	28.50 .09
10 years	Clarinda, Iowa (Marshall silt loam).	June 27, 1933	2.88	10.33	2.84 inches in 280 minutes.	.60	Bare Grass	9.0 9.0	52.7 9.08	2.41 1.35

U. S. Soil Conservation Service photo.

FIGURE 48.—Profile on the watershed of a tributary of Coon Creek, Wis. Since the beginning of farming about 60 years ago, 5 feet of soil material has washed down over the alluvial bottoms. The time required to deposit the 8 feet of material now buried below the dark line may have exceeded 10,000 years. The old alluvium of the preagricultural stage has the uniform character of deposits laid down by moderate floodwaters. The new alluvium has the diverse character of deposits laid down by violent floodwaters.

U. S. Soil Conservation Service photo.

FIGURE 49.—Lake Como, Minnesota in 1926 provided power and water supply, and was the basis of a thriving tourist trade.

U. S. Soil Conservation Service photo.

FIGURE 50.—Lake Como in 1936; a useless swamp after the cutting of timber and extension of intensive agriculture in the headwater valleys caused erosion and siltation.

TABLE 10.—*Comparison of run-off from rains of maximum and average intensities*

Soil and water conservation experiment station, Clarinda, Iowa; period, 1932 to 1935, inclusive

[Average annual rainfall 26.95 inches; various slopes]

Treatment of various plots	Run-off	Run-off from individual rains
	Percent precipitation	*Percent*
No cover, eroded soil:		
Fallow, untreated	27	78
Fallow, manured 8 tons per acre	22	73
Fallow, manured 16 tons per acre	18	66
Average	22.3	72.3
Continuous corn, uneroded soil, untreated	15	100
Do	19	90
Do	25	85
Do	18	61
Do	19	59
Do	21	67
Continuous corn, eroded soil, untreated	22	60
Do	14	56
Average	19.1	72.3
Corn, manured or in rotation:		
Continuous corn, eroded soil, manured 8 tons per acre	10	50
Continuous corn, eroded soil, manured 16 tons per acre	5	43
Corn, uneroded soil, in rotation, following clover	15	65
Average	10	52.7
Close-growing vegetation, uneroded soil:		
Oats, in rotation	9	22
Clover, in rotation	2	6
Continuous alfalfa	6	5
Continuous bluegrass	6	14
Average	5.8	11.8

TABLE 11.—*Comparison of soil and water losses from areas of different size: Marshall silt loam*

Soil and water conservation experiment station, Clarinda, Iowa, period 1932 to 1935, inclusive

[Average annual rainfall 26.95 inches; slope 7.75 percent]

Size of plot	Slope length	Annual soil loss	Average annual run-off	Run-off
	Feet	*Tons per acre*	*Inches per acre*	*Percent precipitation*
0.60 acre	[1] 630 by 42	19.82	1.72	0.064
0.30 acre	[2] 315 by 42	15.64	2.08	.077
0.15 acre	[3] 157½ by 42	11.80	2.83	.105

[1] Equivalent to cross section of field 9.11 acres in size.
[2] Equivalent to cross section of field 2.28 acres in size.
[3] Equivalent to cross section of field 0.57 acre in size.

Some of the available information indicates that under the same conditions of soil, slope, and rainfall, the rate of run-off from large areas does not differ greatly per unit area from that of small areas, for certain types of land at any rate, although the rate of erosion tends to increase, within undetermined limits, with increase of the slope cross section (tables 11 and 12). For example, at the soil and water conservation experiment station in southwestern Iowa (table 11), the run-off from three plots with cross sections corresponding to fields of approximately ½, 2, and 9 acres, respectively, ranged from a rate of 2.8 inches per acre from the smallest

TABLE 12.—*Water and soil losses under different planting methods and areas of different size: Houston black clay*

[Soil and water conservation experiment station, Temple, Tex.]

PERIOD JULY 30, 1933, TO DEC. 31, 1935: SLOPE RANGE EACH PLOT, 4 TO 6 PERCENT

Area	Cropping practices	Annual losses		Rain of May 18, 1935: 3.45 inches		Rain of July 27, 1935: 2.3 inches	
		Water	Soil	Water	Soil	Water	Soil
		Percent precipitation	*Tons per acre*	*Percent precipitation*	*Tons per acre*	*Percent precipitation*	*Tons per acre*
1.38 acres	Cotton, with strip cropping	9	5.2	37.4	0.98	33	0.02
1.39 acres	Cotton, rows on contour	19.6	52.3	57.6	17.2	64.2	12.50

PERIOD 1932 TO 1935, INCLUSIVE; SLOPE 4 PERCENT

Area	Cropping practices	Water	Soil	Water	Soil	Water	Soil
0.09 acres	Corn, with strip cropping	0.95	0.30				
0.03 acres	Cotton, rows down slope	14.46	15.61				
0.05 acres	Cotton, rows on contour	5.80	5.52				

field to 1.7 inches from the largest field, while, in contrast, the rate of soil loss ranged from approximately 12 tons an acre from the smallest field to 20 tons from the largest field.

In a scientifically integrated attack against such losses these relationships are not always as important as they might seem, since the plan calls first for a careful survey of the different kinds of land making up a farm or watershed and the treatment of each kind according to its individual needs and adaptabilities.

CONCLUSION

There is no question, I believe, but that the era of land exploitation and extravagant waste of water resources in this country is rapidly coming to an end. Indeed, I am convinced that we already have entered a new era of husbandry—of wise use of the land and sensible conservation of the water that falls on the land. Steadily the forces of conservation are being woven into a unified program of soil and water control and economic utilization of rainfall. Federal, State, and local agencies and individuals are working in closer and closer cooperation and now, as never before, the people of the country are awakened to the dire national consequences of uncontrolled erosion and unleashed waters.

We are beginning soberly to realize that our traditional American indifference or unsympathetic attitude toward the conservation of natural resources was leading us into a complexity of economic difficulties—good soil and needed water wasted, duststorms, stream channels and reservoirs glutted with silt, record floods. We are learning that we have been a prodigal Nation and that the magnificent natural heritage with which we began our career as a Nation is not inexhaustible. In a new sense we are becoming land- and water-conscious. Now, we finally are beginning to apply common-sense methods of soil protection and common-sense methods of rainfall conservation to declining fields and pastures, with regard to which heretofore we have devoted little thought and essentially no coordinated planning.

That new conservation machines are being manufactured in increasing quantity and variety—machines for conserving soil and water, such as terracers, subsoilers, and basin listers—is but a sign of the times, as I see it. I am convinced the movement cannot be arrested.

In the Soil Conservation Act of 1935 Congress for the first time recognized accelerated erosion as a national menace and declared it to be the policy of Congress "to provide permanently for the control and prevention of soil erosion and thereby to preserve natural resources." Out of this forthright declaration evolved the Federal-State program of soil and water conservation now in progress over far-flung parts of the country.

And the Flood Control Act of 1936 is of historic significance, also; for it is the first time, to my knowledge, that the part of the agriculturist in flood control has been officially and specifically recognized by Congress.

In what I have said to this conference—to you who have joined in this effort to bring together the best ideas and plans of our several specialized fields in friendly cooperation for developing a far-reaching, comprehensive program within the upper limits of watersheds—it will be thoroughly understood, I believe, that agriculture is not proposing a substitute for flood-water fortification downstream. I am convinced you appreciate that what the agricultural specialists are offering is what, in all good faith, they consider upstream reinforcements to downstream operations by conservation work on the land where floods begin and where silt loads are picked up. The immediate task ahead is to agree upon a simple procedure of cooperation and coordination, whereby the engineer and the agriculturist will be working and thinking and planning along the same line, and for a common purpose. When such a procedure is mutually understood and cooperatively put into effect, I am confident that we shall then be definitely on the way to success.

Furthermore, I believe that the way has been marked; the pattern cut. Those who have the vision and the will to move forward in unison—downstream along our major waterways, upstream along the little waters and out into the fields and pastures and wood lots, on the ranges and far into the mountains—will find a supporting hand in the farthermost corners of this progressive Nation.

We must ally our forces to defend ourselves against floods and soil erosion, for these are also allies, but allies in destruction.

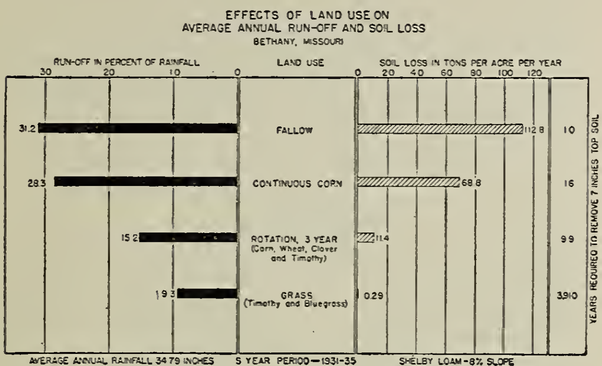
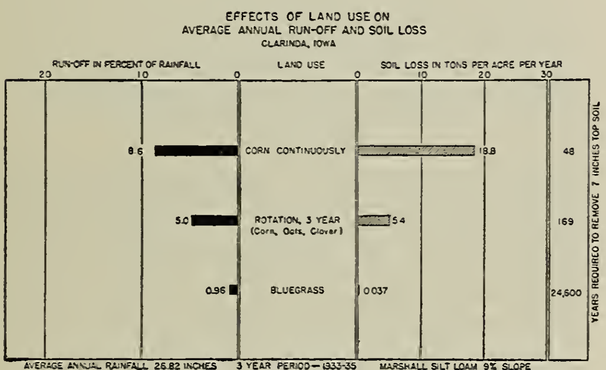


Figure 51.



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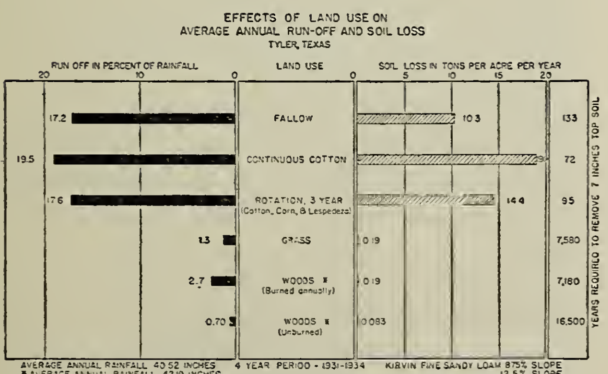

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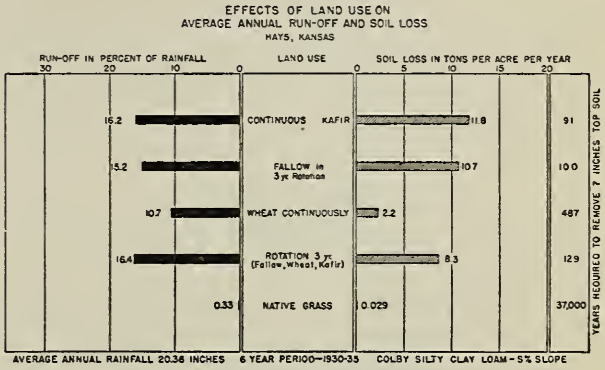

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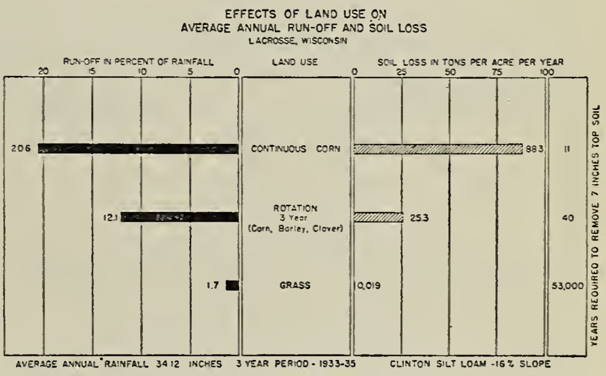

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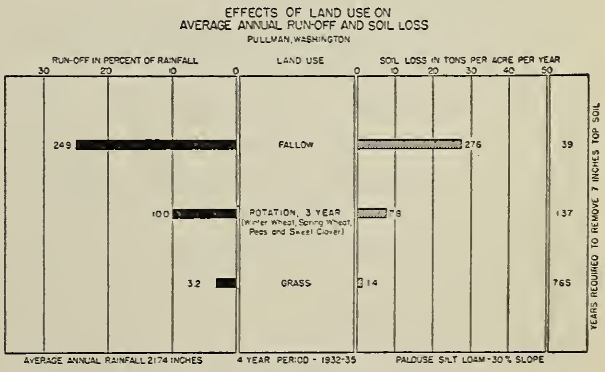

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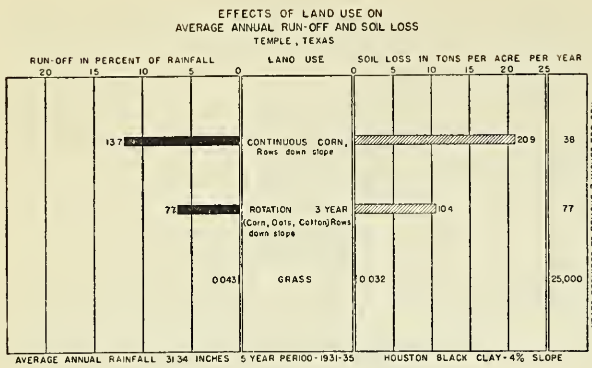

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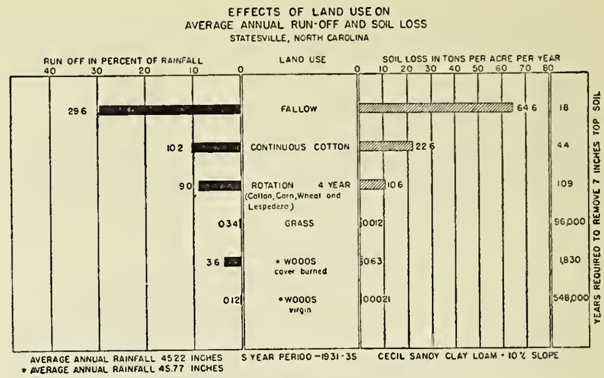

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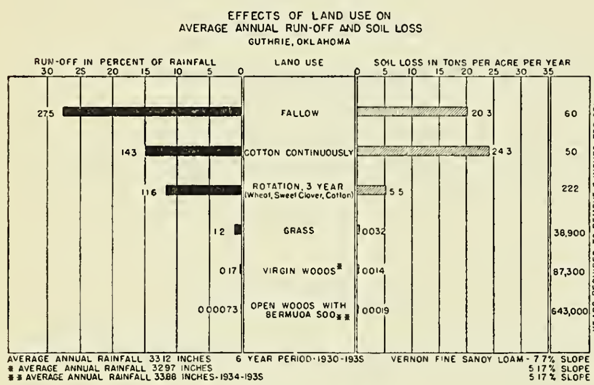

Figure 58.

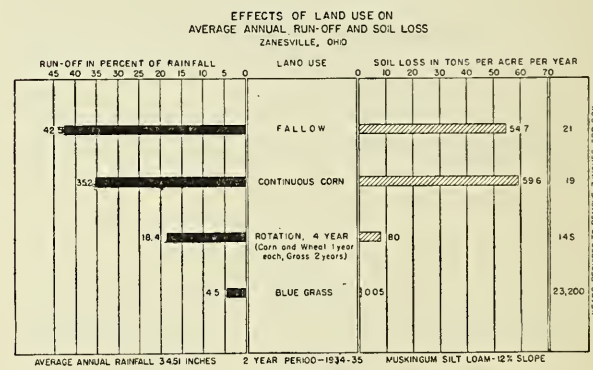

Figure 60

DISCUSSION

1. Noble Clark

Assistant Director, Agricultural Experiment Station, University of Wisconsin, Madison, Wis.

When we learn the wide extent of the erosion-control program being carried forward under the leadership of Mr. Bennett and his associates in the Soil Conservation Service it is hard for us to realize that only 3 or 4 years ago the general public hardly knew there was such a thing as soil erosion. A few States had made a beginning by conducting erosion-control extension work with farmers, and the United States Department of Agriculture had established, in cooperation with certain States, small erosion-experiment stations in the soil areas where erosion was most severe.

Today Mr. Bennett, and those of us who have cooperated with him in his work, face quite a different situation than 3 years ago when the main task was to arouse the public from its apathy, and to win public funds with which to put on demonstrations of what could be done to control erosion by harnessing engineering skill and plant science to the task. Now we have the even more difficult duty of administering a cooperative Federal, State, and local program of soil and water conservation that will not only hold an aroused public interest, but will also win the confidence and approval of taxpayers, landowners, and legislators. We must convince these people that we have thought our problem clear through, and have a program that deserves the continued support of all people and all agencies.

It is highly proper, therefore, that those of us gathered here take counsel together as to the lessons the past 3 years have taught us, and to formulate a working plan that is most likely to

enable us to make the progress in the future that we have the right to expect of ourselves, and the public has a right to expect of us.

In the first place it would seem important that we remind ourselves American agriculture is being carried out on 6,800,000 different economic units, on which are living 31,900,000 farm people. It is these farm families who are in the front-line trenches in this warfare against losses caused by unrestrained water. Our job in conserving soil and water is just as much a task in human engineering as in hydraulic design.

We have been hearing much about the building of dams and terraces, as well as the planting of trees and of grass. It will be well for us to have an understanding as to who is to do the building and the planting. In other words, how much of the labor and expense of water and erosion control on privately owned land have we a right to expect the landowners to carry?

There is little difficulty in getting farmers to prevent or control erosion when some governmental agency does the work and pays the bills, all with only minor cooperation from the landowners. Our urgent need is to determine at what stage of soil depletion, to what extent, and for how long this governmental assistance should be given. Likewise, we must decide whether we can afford to run the risk of the farmers backsliding when the governmental aid is withdrawn. There is much evidence to support the belief that a large portion of the work required to control erosion will be repaid to the landowner in increased yields. Certainly farmers have a direct personal interest in reducing erosion, and landowners in all fairness should be required by the public to furnish the labor and money to offset the immediate benefits they receive from erosion-control programs.

But how are we to make certain that farmers actually make their contribution to the Nation-wide cooperative effort that is required if we are to attain our goal? It is obvious that some positive inducement or compulsion is going to be necessary. The best research talent at our disposal should be put at work to devise the legal machinery which will insure that landowners actually do their share of the work, and make their share of the sacrifices, because the alternative of having the Government pay for all erosion and water-conservation activities would bankrupt the Nation.

Telling farmers how to control erosion, and why they should do it, is absolutely necessary, but we have found from experience that education and persuasion alone do not suffice. We have had for 25 years an efficient agricultural extension service in every State in the Union. This service has given much attention to erosion control, but the number of eroded acres has grown and grown. Clearly the need is for effective legal and economic methods that will require landowners to do their just portion of the work of reducing the loss of soil and water from American farms.

It is my conviction we need to spend a larger portion of our efforts in preventing erosion from getting started on what are now relatively unimpaired areas. It is on the rougher and poorer lands that the major erosion losses have occurred, and it is natural that we have given these lands our first attention. However, if the present exploitive systems of land use are continued the better agricultural areas will soon be in distress, and we will be having correspondingly increased demands for governmental assistance to help landowners control situations that have become too difficult for them to handle unaided.

It is a peculiarity of the erosion problem as it affects farm lands that in its early stages, while it can be checked quite easily, erosion does not sufficiently impress farmers with its seriousness, and hence they usually ignore it. During the later stages of erosion the damage has become widespread, and the whole community is jeopardized, but by this time individual farmers cannot cope with it adequately, and public assistance is required.

Today most of our efforts and demonstrations are being directed at correcting or curing the

bad results of erosion. Undoubtedly we need to continue many of these efforts at rehabilitating eroded lands, but in the meantime I am convinced we should take vigorous steps to prevent additional millions of acres from passing into the classification of areas on which erosion represents a problem so acute as to require substantial governmental assistance to the landowners. We must not wait until the harm is done before we have a program that really works. In this respect erosion is similar to so many other undertakings—prevention is infinitely cheaper and much more effective than attempts at cure.

It is on these large areas of good soil as yet only slightly injured by erosion that we particularly need a legal device for insuring that the landowners do their fair share of the work, and make their fair share of the sacrifices, required to put into effect a satisfactory program of soil and water conservation. But the leadership in formulating such a protection and prevention program rests on the Federal and State agencies. The major portion of such a program should be education, with the compulsion feature brought into play only when required to secure the cooperation or compliance of the exceptional individual who will not act, even to protect his own farm, except when society presses him to do so.

I do not have a blueprint of the legal devices that would most nearly fit the needs of the situation, but I know there are many possibilities in this field. For instance the tax rate on farm lands could be at a somewhat lower rate when proper erosion control practices were being followed, or at a higher than average rate when the landowner was following land use policies that definitely increased erosion. Still another example is the weed law on the statutes in many States. This law provides that if the landowner fails to remove the weeds himself, a governmental agency shall enter a farm and destroy noxious weeds, and the cost will be added to the tax bill on the property.

The Texas Legislature has passed an act giving counties the power to establish a conservancy district when necessary to construct improvements required to protect private lands from injury by erosion and to assess the cost of the same against the lands so protected and benefited.

It remains to be learned if the courts will sustain this act, but the principle is certainly sound, and we need careful study to develop similar laws to fit the peculiar legal restrictions that make each State a separate problem in this respect.

There is abundant precedent for the enactment of laws which will require landowners to practice reasonable control of erosion, so as to protect adjoining lands and the public interest in general. The immediate task is to determine the exact administrative machinery that will likely prove the most efficient; and to win the support of the voters to the enactment of the necessary legislation. However, such legislation will be no more effective than the degree to which public opinion in the various farming communities believes in the purposes of the law, and is willing to support its enforcement. Here again the big job will be education, for I have absolutely no confidence in anything worth-while being accomplished if such legislation is passed by Congress or by the several State legislatures, unless there can be developed in each rural community an active desire to have the law enforced because the great majority of the local people realize it is to their own interests to have it enforced.

In our educational program we should always remember that farmers are frequently hampered by factors that are completely beyond their control. Few things exasperate farmers more than to read a statement which gives the impression that erosion is caused by farmers who abuse their land; that the control of erosion has all been worked out by governmental specialists; but solely because the farmers are unwilling to adopt the recommended practices, the erosion goes on.

Our research in Wisconsin has shown that the operator of a large farm is usually much better able to practice soil and water conservation than the man on a small holding. The limited acreage of the little farm does not give the operator much flexibility. He often needs to crop every acre of it to utilize his labor and give a minimum farm income. To ask such a farmer to retire the steeper portion of his farm from cultivation, and to plant it to trees, is simply out of the question so far as this man is concerned. If we are really going to get results with this erosion-control program we will have to make some intensive economic and farm management studies to learn how to make adjustments to the situations individual farmers face. We cannot solve the problem with engineering devices and plant cover alone. There is just as great need in this undertaking for land economists as for engineers, foresters, and agronomists.

Then there is the land tenure factor that plays such a large part. All of us recognize that a tenant who has a short-term lease has every incentive to get all he can out of the land, and to let the future go hang. It should be obvious that in areas where much of the land is operated by renters we cannot expect to meet with success in our soil and water conservation program unless and until we have laws enacted which will provide incentives to tenants to practice erosion control, and guarantee to them at the completion of their leases a reasonable return or reward for what they do to conserve soil and water.

My next point deals directly with soil management, and I am raising the issue not as a technician but as a layman who has been much impressed by its importance. One of the Nation's most distinguished soil scientists has told me that over half of the soil erosion in this country is due to depleted soil fertility. Improper cropping practices have destroyed much of the organic matter in the surface layers of the soil, which, together with the failure to replace plant foods removed by the crops, have caused crop growth to be puny and sparse. In this manner the vegetative cover so essential to erosion control has been critically reduced. Under these conditions erosion begins insidiously, but soon spreads like a veritable contagion.

The significant implication is that erosion is both a result and a cause of low crop yields and a decadent agriculture. Nearly all of the farming areas which have been destroyed by erosion were first made vulnerable by farming practices that seriously depleted the humus and plant food in the soil. Erosion was the second stage in the soil-destruction cycle. Truly fertile fields, unless they be on very steep slopes or are wantonly mismanaged, rarely suffer from serious erosion.

The great bulk of the agricultural production that finds its way to our central markets is raised on reasonably level or gently sloping lands which do not erode seriously when such soils are maintained in a good state of fertility and are cropped according to any intelligent rotation system.

We Americans have drawn check after check on the credits of phosphorus, potash, and nitrogen in our soil bank, but we have made few deposits. All of us know you can do this for a while, but sooner or later such a policy leads to serious trouble. An overdrawn account is usually a painful experience. The real tragedy, when farm operators overdraw their deposits in plant food and soil fertility, is that they not only lose their soil fertility, but actually the soil itself, because of erosion.

To stop this will require a right-about policy on the part of most American farmers. It will mean building up the organic matter and fertility of their soils. I do not think I overstate the case when I say that any water and soil-conservation program to be really effective must build up and maintain soil fertility. Fields devoid of humus, and low in plant food, are almost certain to erode. But improved fertility will mean increased yields, and eventually a much

greater aggregate national production of agricultural products.

Today we have two soil-conservation programs sponsored by the Federal Government. One is an attempt at harnessing science to the task of preventing soil erosion, and encouraging water to soak into the ground where it falls instead of running off the land and taking the soil with it. This is the program we are discussing at this conference.

The other program also carries the title of soil conservation, but behind this title there seems to be the objective of controlling agricultural production in such manner as to permit farmers to secure a larger portion of the national income. Many persons have grave doubts as to whether this second program is significantly reducing erosion or conserving water. You probably know that under this program a farmer can receive the maximum cash benefit payments, and actually follow the practice of moving all his cultivated crops to the steep slopes on his farm, and put his pasture and hay on the level land.

Farmers are entitled to their fair share of the national income, but those of us who carry responsibility for leadership in soil and water conservation cannot avoid regret when farmers are encouraged to believe that successful soil conservation can be attained by simply increasing by 5 to 15 percent the farm acreage planted to grass.

We need the public's confidence in the sincerity and soundness of the Government's attempt at soil and water conservation. This will require a complete separation of the two programs now carrying the same name, but with radically different objectives. One program, our program—calls for the increase in soil fertility and the enlargement of crop yields so as to reduce erosion. The other program seems to aim at restrictions in agricultural production so as to control prices and thereby give economic aid to farm people. The two programs are not closely related; in fact they simply are not bedfellows. Both programs will be immensely benefited if the present confusion in titles and announced objectives can be clearly differentiated.

I was glad to hear Mr. Bennett make his plea for additional research in methods of conserving water and soil. It is my understanding the Soil Conservation Service is now spending not less than 25 millions annually. A very large educational and field program is underway. The sad fact remains, however, that these field programs have now caught up with the findings the modest research program has been able to secure. In more than one instance I have personal knowledge that the Operations Division is ahead of the Research Division. Likewise it has been necessary for the Operations Division to lay out plans for private landowners in which certain untested procedures were incorporated.

For example, the Soil Conservation Service has signed agreements with farmer cooperators in Wisconsin and Minnesota that require the landowners to strip crop over 100,000 acres of their land. Yet there has never been any research on a field scale in the upper Mississippi Valley to learn the difference in effectiveness of field strips of varying widths, nor whether laying out these strips at a slight slope will not be much more effective than placing them exactly on the contour. We are even unable to give farmers any quantitative answer when they ask us how much they can expect strip cropping to reduce water and soil losses, and how strip cropping compares with terracing in this respect. We are certainly justified in continuing to advocate strip cropping, but just as certainly we have the obligation to work out on a research station how best to lay out a system of strip cropping, and should, without further delay, accurately measure the effectiveness of strip cropping on a field scale.

We especially need research in the economic field. Who knows but what our erosion control programs are saving our soil at the expense of greatly increased labor on the part of farm families? Farmers who are asked to cooperate

in the program want to know how much more work it will be to operate their farms after their fields have been reorganized according to our plans. We should have accurate information, based on the experience of many farmers, that will enable us to give clear cut answers to this question. Maybe the reverse is true, and such procedures as plowing and cultivating on the contour actually decrease farm labor costs. If this is so it would be invaluable information to have in our educational work with landowners. We should secure these data without further delay, and with just as much accuracy as we determine the capacity of one of our engineering structures to carry its load of water.

We likewise should discontinue the practice of building our operations staff organization by transferring to it the older and more competent men engaged in erosion research. No successful business organization like General Electric or American Telephone & Telegraph would thus rob its research to build up its operations division. We must remember that the operations program is built on a foundation that can only be supplied by research, and that the success of the field program demands that research be given primary consideration and financial support.

I am convinced that insufficient research is the biggest handicap to our water and erosion-control program, and that we cannot afford to continue the present division of funds which leaves research unable to equip the operations program with the new facts and principles that are necessary if our work is to be effective and lasting. Legislative bodies should protect present field programs in erosion and water control by supplying funds for the support of the urgently needed research.

2. Samuel H. McCrory

Chief, Bureau of Agricultural Engineering, U. S. Department of Agriculture, Washington, D. C.

The management and use of agricultural lands has a profound influence upon the national economy. Dr. H. H. Bennett has discussed in a most interesting manner this important problem and has raised some questions, the answers to which are not readily apparent. As he has pointed out, the problem of preventing or controlling erosion on agricultural land has had considerable study and in his paper he has presented some very interesting data in regard to the valuable effect of vegetation, particularly grasses and forests in reducing the amount of erosion.

It has always seemed that the most difficult problem in the control of erosion was that of reducing the amount of, or preventing erosion on, land planted to cultivated crops. We must grow crops to provide food and clothing. Their production requires that we prepare the seed bed, plant the seeds, and in the case of crops such as corn, cotton, and potatoes, cultivate the plants. Seed-bed preparation and cultivation produce a condition favorable to erosion. Studies made under the writer's direction at Raleigh, N. C., show that for a 3-year period from 1924–26, inclusive, 86 percent of the soil erosion, 64 percent of the water run-off, and 45 percent of the rainfall occurred during the months of June, July, August, and September. Similar conditions undoubtedly occur on all cultivated lands but the time of greatest danger depends upon the crops grown, the tillage practices followed, and the occurrence of high rates of precipitation. For example, with cereals planted in the spring, the period of danger of severe erosion extends from the time the land is prepared for cultivation until the crops have established themselves sufficiently well to afford protection to the land upon which they are growing. In the Palouse country in Washington, melting snow is apt to cause severe erosion. Other agencies working on this problem have substantiated this conclusion. Various means of protecting such land from erosion are in use. It would have been most interesting if Dr. Bennett had presented the complete data upon which he bases his conclusions in regard to the

efficiency of strip cropping and contour furrowing, as very little systematic data have been made public in regard to the measured results obtained from these practices.

One of the time-tested ways of controlling erosion on cultivated land is terracing either alone or in combination with other control practices. As Dr. Bennett included no data in regard to the efficiency of terraces in protecting cultivated land, the writer believes it will be of interest to this conference if he summarizes briefly some of the results of the efficiency of terraces which were obtained under his direction. On the experimental farm at Guthrie, Okla., the average annual soil loss for 3 years from an unterraced area was 64.1 tons per acre while the average annual loss was 2.2 tons per acre from a terraced area, on which the soil was practically the same and the crops were essentially the same. At Tyler, Tex., soil losses per acre for 1933 were 3.4 tons from a terraced area and 41 tons from an unterraced area with gullies controlled by brush dams, both areas having land slopes of 7½ percent. At this station water and soil losses were small from terraced pasture land as compared with terraced cultivated land. Terraces on cultivated land lost 4.74 times as much water and 26.9 times as much soil as terraces on comparable pasture land. At Statesville, N. C., the loss from a terraced field was 2.3 tons per acre compared with a loss of 23.2 tons per acre from an unterraced field. At Bethany, Mo., an unterraced cornfield lost 27.1 tons of soil per acre during 1933 as compared with 3.8 tons per acre from a similar terraced cornfield. In general, the experiments showed that terraces materially reduce soil erosion losses and that the losses from terraced land in terms of the losses from unterraced land range from 3.4 percent at the Guthrie station to 20 percent at the Pullman station. Losses increase appreciably with the grade of the terrace. Level terraces are more effective than graded terraces in conserving water and soil, but damage to crops results from excessive wetness often occurring in impervious soils in the level terraced channels and level terraces. Both soil and water losses are greater for uniform than for variable graded terraces. Soil losses increase as the length of terrace increases, making it desirable to use short length terraces as much as possible. Also losses tend to increase with increase in terrace spacing on cultivated land. Not much dependence should be given on grain crops, such as wheat, to control erosion. During the growing season erosion is appreciably checked by such a crop but heavy erosion losses are liable to occur from the time the seed bed preparation begins until the crop is large enough to minimize erosion. These results were obtained from terraced fields on which contour farming was practiced. A rotation of crops was used which was perhaps somewhat better from an agronomic standpoint than that common to the several regions. The experiments are still, in part at least, being carried on by the Soil Conservation Service.

Our experience with terraces has shown that they need to be fitted to the soil and topography for which they are used. The large amount of demonstration work now being carried on by the Soil Conservation Service is giving all erosion control methods the test of extensive use and should result in steady improvement in the design and construction of terraces and other erosion control devices. There is need for much further research looking to the development of improved machinery for the construction of terraces. While progress has been made it seems apparent that in the next few years much greater progress will be made and equipment devised which will be more efficient and economical in building terraces.

It is the writer's opinion that not too much should be expected from water conservation practices in the semiarid regions as the amount of run-off in these regions is normally small and at times extremely low. For example, run-off from the Souris River at Minot, N. Dak., in the lowest year of record was less than 1,000 acre-

feet from a watershed area of over 10,000 square miles. There are, however, many small areas where practices similar to those followed at Spur, Tex., could be followed to advantage. But it must be recognized that only a small percentage of the land can be benefited as the amount of run-off is very small in many years. While water conservation measures may help, they can only use available precipitation and run-off. They do not create water. Much benefit to local communities can, however, be obtained by the installation of small dams at suitable locations to hold back water in small water courses. These are valuable as a source of water supply in times of drought and have a certain value for recreation and wildlife. It is the writer's opinion that more consideration should be given to the use that can be made of ponds, reservoirs, and streams in connection with the maintenance of wildlife. Some of the larger reservoirs and other structures afford opportunities for providing refuges for wildlife at little cost, and should be taken advantage of to the fullest extent. It is not necessary that fixed water levels be maintained on such refuges but a minimum level should be provided which will afford at all times conditions suitable for wildlife and particularly migratory waterfowl. Arrangements for such use have been made in the case of Lake Mead on the Colorado, Tule Lake in Washington, and Deer Flat Reservoir in Idaho. The Pymatuning Reservoir in Pennsylvania affords perhaps the most outstanding example of a development of this kind. There is very great need for such developments particularly in the area between the Mississippi River and the Atlantic coast. In this region there are few places where migratory waterfowl can rest, and frequently when they find it desirable to pass from the Great Lakes or the Mississippi River to the Atlantic coast they are compelled to make a nonstop trip.

The physiographical balance of watershed areas is frequently a condition of delicate adjustment and a change in conditions may have far-reaching results—some beneficial, some detrimental. In the West where irrigation water is the limiting factor in agricultural production any control measures which tend to reduce available water supply may seriously interfere with agriculture. Data indicate that the vegetative cover within limits makes use of the available water. We do not have a precise measurement of the amount of water required to produce crops but some idea of their requirements is given by duty of water studies reported by Dr. Samuel Fortier, formerly chief of the Division of Irrigation, Bureau of Agricultural Engineering. Data collected under his direction for the arid and semiarid regions of the Missouri and Arkansas River Basins and the semiarid land of the Southwest are given in tables 13 and 14.

TABLE 13.—*Average range of water requirement of crops including rainfall of the arid and semiarid lands of the Missouri and Arkansas Basins*

Name of crop	Number of tests	Water requirement (acre-feet per acre)	
		Average low	Average high
Alfalfa and other forage crops	648	1.94	2.62
Potatoes	350	1.38	1.70
Sugar beets	128	1.60	2.50
Wheat	542	1.36	1.80
Oats	409	1.35	1.81
Barley	335	1.33	1.82
Corn	70	1.23	1.83
Kafir corn	15	1.43	1.57
Millet	14	.81	.94
Milo maize	27	1.09	0.70
Sorghum	26	1.06	1.47
Beans	4	1.30	1.60
Flax	50	1.47	1.86

From *Irrigation Requirements of the Arid and Semiarid Lands of the Missouri and Arkansas River Basins,* table 5, U. S. Department of Agriculture, Technical Bulletin, No. 36.

These data show that water requirements increase as one goes South and give an indication of the amount of water required to produce different crops. It is probable that cultivated crops in the humid region may use more water than native vegetation although certain kinds of water-using plants transpire large amounts of water, as is indicated by measurements made in various parts of the United States.

TABLE 14.—*Water requirement of crops in the Southwest, including irrigation and rainfall*

Crop	Tests	Water requirement, per acre	
		Lowest general average	Highest general average
	Number	*Acre-feet*	*Acre-feet*
Alfalfa	369	3.47	5.08
Barley	3	1.24	1.83
Beets (table)	28	.87	1.37
Beets (sugar)	5	1.77	2.72
Corn	42	1.44	1.99
Cotton	103	2.35	3.51
Flax	3	1.23	1.59
Kafir	16	1.32	1.54
Milo	35	.96	1.67
Millet	5	.91	1.09
Oats	2	1.90	2.09
Potatoes	12	1.59	2.04
Wheat	46	1.46	2.24

From *Irrigation Requirements of the Arid and Semiarid Lands of the Southwest,* table 4, U. S. Department of Agriculture, Technical Bulletin, No. 185.

3. George E. Condra

Dean, Conservation and Survey Division, University of Nebraska, Lincoln, Nebr.

Dr. Bennett's well-prepared paper merits only favorable criticism. I am in full accord with its content and appreciate the fact that the author did not have time to cover the whole of the subject as fully as his experience and knowledge would warrant. His paper was restricted largely to soil and water conservation with the hope and request that the discussors might consider certain additional factors in land management and use.

It would be presumptuous for me to assume to reiterate, criticize, or attempt to explain further the salient points that were so well presented by Dr. Bennett. The picture he gave of the ravages of soil erosion, of the need for soil saving, of the methods used in erosion prevention and water conservation, and of the relation the Soil Conservation Service holds to the future agricultural development and welfare of our country is impressive and convincing.

My discussion will fall in line with a request made by Dr. Bennett. It will be a brief review of: (1) The changed landscape, (2) mistakes and adjustments, (3) the ground-water factor, (4) agricultural forestry, and (5) basic survey and research.

CHANGED LANDSCAPES

Our agricultural lands were formerly covered by grass or by forest, both of which have been largely destroyed and replaced by cultivated crops. This change in landscape began in the East and progressed westward. Since our predecessors had little technical guidance from Federal and State agencies regarding the management and use of land, they accomplished the things that were thought to be necessary and right under the conditions of their day.

It is now well established that the removal of topsoil and the depletion of humus have disturbed soil-moisture relationships on certain types of agricultural land with the result that absorption has decreased and surface run-off increased. It is also known that in many places much ground water is being drained away, the water table lowered, and vast quantities of soil-forming material and useful water wasted. The widespread wastage of land and water resources through the years has reduced the carrying capacity and value of the land to an alarming degree and has developed problems of national importance.

Evidently some of the badly eroded land cannot be restored to its former producing capacity, yet there are large areas of it that can be reclaimed under proper management, as is evidenced by the success attained on many farms and public demonstration projects. It is believed, therefore, that under proper management much of the general landscape will again approximate its former beauty and agricultural and related developments can be adjusted and stabilized on a permanent basis.

MISTAKES AND ADJUSTMENTS

It is plainly evident that mistakes, failure, and discouragement have come to many areas because of the lack of adjustment between agricultural practices and natural environment. It

is imperative that we recognize these conditions and discover methods whereby necessary adjustments can be consummated. These widespread conditions present two major problems, viz, the conservation of our natural resources and the conservation of people. Fortunately, the situation is being evaluated and a comprehensive program of adjustment and stabilization, based on farming experience, technical information, and a plan to use lands and waters for their best purposes, is under way.

I will refer to some of the mistakes and adjustments that have been made in land use in Nebraska where experimentation along these lines has been under way for several years. All of the lands in question were settled and put into agricultural use before the factors—climate, water, and soil—were evaluated by survey and research. However, during recent years all of this land has been described by the geological, soil, and water surveys. The agricultural experiment stations have accumulated valuable data relating to the natural uses that can be made of lands according to their condition of occurrence and adaptabilities. So we have the results of the investigational activities and the experience of farmers, as a factual background, for shaping the adjustments that should be made in the management and use of lands in Nebraska.

It is now generally recognized that there is wide diversity in climate, topography, soil, ground water, wildlife, and agricultural possibilities within the State, and that the future use of the land will be determined, more than in the past, by the dominant environmental factors. It is recognized that all of the land of the State is adapted to some use and that the big problem is to conserve the water and soil resources for the best use that can be made of them.

I will now refer to the degree of adjustment that has been attained with five types of land in Nebraska, i. e., with areas of (1) sandhills, (2) shale hills, (3) loess hills, (4) loess plains, and (5) tablelands with thin, sandy soils. Time will not permit a review of the adjustments that are being made in the management and use of sandy flood plains, terraces, rough lands, smooth tablelands, small alkalied areas, flood lands, and irrigated lands.

Sandhill land.—About 20,000 square miles of Nebraska are occupied by sandhill areas. The conditions of these areas are summarized as follows: Mantle rock and porous bedrock extend to depths of 300 to 1,000 feet and rest on impervious beds; the topography is hilly and is modified by basins and valleys; soil and subsoils are sandy; rainfall ranges from 17 to 24 inches, decreasing westward; the natural plant cover consists primarily of grass, small shrubs, some trees and aquatic forms; the rate of rainfall absorption and downward percolation is high; there is no surface run-off for about 90 percent of the areas; ground-water storage is very great with a high-lying water table; ground-water run-off is relatively high and provides streams with a uniform discharge; there are over 2,000 shallow lakes and marshes, the depth of which varies with the height of the water table.

Formerly, plowing and overgrazing resulted in much wind erosion on this natural prairie land. It is well suited to grazing and is now used primarily for cattle raising, the hills affording pasturage, the basins and flats producing hay for winter feed, and the shallow ground water supplying water for wells. The minor uses of the sandhill areas include forestation, State recreational areas, wildlife preserves, and habitat for ducks, grouse, prairie chickens, fish, and fur-bearing animals.

The main physical problems in the sandhill areas involve the maintenance of uniform grass cover on the hills, the optimum depth of water table on the hay flats, and the preservation of the lakes against drainage and evaporation. Ranch management in these areas has assumed a high degree of adjustment and standardization and only high-grade animals are raised.

Shale land.—An area of about 600 square miles in northwestern Nebraska is defective for agricultural use. The natural conditions of this

area are: Shale (Pierre) extends from the surface to a depth of 1,200 feet or more; the topography is hilly, modified by small valleys; the soil is thin and clayey and is known as gumbo; rainfall varies from 16 to 18 inches; natural plant cover of the area consists of the grass and shrubs; the rate of rainfall absorption and water penetration is low; surface run-off is rapid and relatively high; the ground-water storage is very little and of poor quality except at depths of 2,000 feet or more. This type of land, of which there are small tracts elsewhere in Nebraska and larger tracts in the Dakotas, has been overestimated in its potentialities and has been badly managed. Among its main drawbacks are the absence of well water, and insufficient soil moisture during dry years. Too much of the land has been plowed, and large areas of it are now abandoned.

These shaly lands, in their natural condition, grow quite uniform stands of grass suited for grazing. Stock water is supplied by impounding run-off. The Pierre shale lands present a problem in resettlement in which the ranch buildings are being located only where potable water can be had and there is some soil suited to cultivation. Generally this type of land can be used best by fencing large pastures, by impounding stock water, and by conservative grazing.

Hilly land with deep mantle-rock.—Large areas in eastern Nebraska, Iowa, northern Missouri, northeastern Kansas, and other States farther east are occupied by hilly land with deep mantle-rock. The hills are deeply mantled with loess or drift, or both. Formerly they had very productive soils and were underlain at most places by adequate ground water of good quality. The original plant cover was grass, shrubs, and brush or trees. Although most of this land is now successfully cultivated except during severe drought, the slopes of the steeper hills have lost most of their topsoil because of sheet erosion and the small drainways have become badly gullied, separating the farms into small disconnected areas. As a result of this erosion the agricultural value of the hilly land has been greatly reduced.

Fortunately these lands are deeply underlain with rich soil-forming materials and by following well-known methods it is possible to rebuild the soils. Unfortunately some of the landowners are slow to make the adjustments required to conserve the land. The problem relates primarily to the correction of the eroded hillsides and the gullies. This can be accomplished effectively by methods that have been used by some farmers and are being used by the Soil Conservation Service. Evidently steep hillsides should be revegetated to grass or trees because some slopes are even too steep for plowing on the contour. Revegetation of the eroded hillsides with grass can be accomplished in the following sequence of operations: First, by seeding to sweetclover; second, to brome grass; and third, to native grasses. The gullies can be filled and obliterated by the use of dams and retards after which the small draws, through which they extend, should be regrassed and used for grazing or hay production.

Loess plains with clay-pan subsoil.—An area of several thousand square miles in south-central Nebraska is a nearly level plain with silt loam topsoil and a heavy subsoil resting on thick loess. The rainfall amounts to about 20 inches in the western and 28 inches in the eastern part of the area. Rainfall absorption is fairly high with penetration to the clay-pan subsoil, which limits the effective soil-moisture storage. Very little of the local rain penetrates to deep water storage. In fact, the well-water supply, which is abundant for farm and municipal supplies, is largely supplied by underflow from the Platte Valley.

The dominant, limiting factor in the use of this area of Nebraska is the clay-pan subsoil, which, as noted before, lies close to the surface and limits the soil-moisture storage. During average years, the region is well suited to general farming, but during drought it suffers considerably. Although there is no water-erosion problem here, some damage is done by wind erosion during dry years when the vegetative cover is sparse.

Adjustments to the environment are being made in this region by growing quick-maturing crops, by thinner seeding, by deep subsoiling which adds capacity for soil-moisture storage, and by irrigation in the western part of the region with floodwater and storage water from the Platte.

Tablelands with sandy soil.—Practically all of the smoother tablelands of Nebraska with deep, fine-textured soils are under cultivation, but the tableland areas with shallow, sandy soils are droughty and cultivation has failed. They blow badly when the sod is broken and contribute to the well-known but unpleasant duststorms. It is now agreed that all such land should be revegetated to native grasses and used for conservative grazing. All of this land is underlain with a good well water at depths of 100 to 300 feet.

Costly lessons.—It is now recognized that the land of Nebraska was placed under cultivation too generally and with too little regard for the character of the soils and the climatic conditions under which they occur. However, the people now know from experience, that all of the land is not suited to cultivation, and that the best of it varies greatly in its adaptability for cropping. Certain results—good and bad—have been obtained, and the valuable lessons learned are being used in formulating effective land policies.

Survey and extension service.—The conservation and survey division of the university has been active for about 26 years in a study of the natural resources of the State. It has made geological, soil, water, and biological surveys over most of the State, and its maps and reports are now available for use in further study. A preliminary land-use map has been made of the State by the division, and a more detailed map of this kind is being compiled. The new map and a bulletin on land utilization are to be published soon. They will give a detailed inventory of the land resources and should be of use in formulating a land-use program for the State.

The agricultural experiment stations, cooperating with the United States Department of Agriculture, perform a notable investigational service in the development of crops suited to the various regions of the State, and in the improvement of cultural methods. The success attained with wheat, alfalfa, and corn is well known, and the studies relating to other rural enterprises contribute to the standardization of land use.

Based on the results of survey, research, and experimentation, the agricultural extension service leads in educational work relating to the agricultural development of the State. This is done in cooperation with the Soil Conservation Service and other Federal departments.

USE OF FERTILIZERS

Many of the leading agricultural soils of the United States are deficient in chemical materials or they have defects that can be corrected by the application of chemical materials. Consequently, there is an extensive and growing need for fertilizer materials, which, except the potash salts, are quite well supplied from domestic sources. Fortunately, extensive deposits of rich potash-bearing materials have been found in New Mexico and other States in the past few years. Our fertilizer preparedness is now quite secure, a condition which will have far-reaching importance in soil improvement and land use.

THE GROUND-WATER FACTOR

Next to the soil, ground water is a dominant element in the success of the agricultural enterprise. It has intimate relations to the value and use of farm land and the comfort and happiness of farm life. I refer in this connection, not to soil moisture but to the ground water that is the source of springs and well water. The depth, quantity, and quality of this water vary greatly in the different types of land and sometimes on a single farm.

Lack of ground water.—There are many farms with inadequate water supply. Large shaly land areas in some States, as in northwestern

Nebraska and South Dakota, have little or no well-water supply except at great depth. As noted before, these areas and similar areas in other States are defective and condemned for cultivation because of the lack of ground water and should be given over to grazing. Water for stock is obtainable by impounding run-off.

Water table.—Much is being said these days about the lowering of the water table and the rapid depletion of our ground-water resources. Although such discussion is timely and warranted, it does not represent the conditions correctly at all places and at all times. What is needed in most States is a ground-water depth survey to be made at regular intervals through a period of years. Such a survey affords reliable information regarding the recharge, storage, and depletion of ground water.

Use of flood water.—Another way to effect better land use would be by the use of flood water for the recharge of ground-water supplies. Structures may be installed in drainage canals and in the borrow pits of highways to hold the water table at its optimum for subirrigation and to prevent the wastage of ground water by drainage during dry years or during drought. Such control measures would counteract the bad effects of the drainage works during drought.

Farm wells.—The Federal Government determines the dependability and potability of ground water in areas before they are purchased for the development of farmstead or resettlement projects. This procedure might be followed more generally on privately owned lands. If this were done, the wells might be better located with respect to the water-bearing formations, and with greater freedom from dangerous ground-water pollution from lots and other sources. As a rule, most rural water supplies are not very safe for drinking and the conditions affecting them should be studied more generally and systematically by State and Federal agencies in order to improve and conserve rural life.

Artesian wells.—At places in the subhumid areas where shallow wells fail because of drought or overdraft, water supplies are obtained by drilling to artesian aquifers, as in northeastern Nebraska, northwestern Iowa, and South Dakota. Although these deeper wells afford a dependable water supply for many farms, the wastage of their water by uncontrolled discharge reduces the ground storage, head, and yield to a point where pumping is necessary. The conditions in the interior States and on the coastal plains along the Altantic, the Gulf of Mexico, and the Pacific have interstate relations that call for the enactment of regulatory measures for the conservation of artesian waters.

Salt-water pollution.—In some States, as Kansas, Oklahoma, and Texas, the unrestricted discharge of heavily mineralized water from wells drilled for oil and gas has caused some pollution of the surface and shallow ground waters. Much land has been destroyed for agricultural use by the salt from these wells, and, at many places, the strong brines are still allowed to invade the shallow water-bearing formations from which rural and urban supplies are drawn. However, the salt-producing wells are now being controlled in a few States.

AGRICULTURAL FORESTRY

Trees, like the native and cultivated grasses, have an important though neglected role in the management and use of land. For very obvious reasons, we should grow more trees and shrubs on our farms, ranches, and rural school grounds. This will require an agricultural forestry program for the Prairie Plains region as an integral part of our conservation program. It would constitute an important physical and social contribution toward the maintenance and improvement of agriculture within a vast, nationally important agricultural area.

For the past 30 years the Federal Government has carried on a forestry program for the conservation of timber and other resources, mostly on Federally owned land where forests occur

naturally. However, the time has come when both agriculturists and foresters must realize that there is another phase of forestry which has to do with the proper management of agricultural lands, where the problems involved concern the relationship of trees to the maintenance and improvement of soil, the conservation of water, wildlife, livestock, and those intangible social benefits relating to human comfort and the increased happiness of living. Agricultural or farm forestry in the Plains States must cover a wide area characterized by variations in climate, topography, ground water, soil, population, and types of agriculture. Therefore, it is necessary that a sound program be provided not only for different types of planting, but also for different methods of application. For these reasons, such a program should be organized by that service of the Government which concerns itself with the Nation's forest problems in general. Primarily from the standpoint of water conservation, there is a direct relationship between the Nation's large forest areas and general agriculture.

National, State, and industrial interests would be affected directly by such a program, and therefore the program should be on a truly cooperative basis, including such interests as the following: The various Federal departments involved in conservation; the many interests in the States, such as individuals, universities and colleges, and State departments of forestry; and the commercial nurseries which are now and have been for years interested in this type of development and improvement work.

The program should be on both a project and educational basis—on a project basis where necessary to improve the physical resources and stabilize agriculture on areas sorely in need of such work, and where deterioration should be checked at the earliest possible moment; on an educational basis for landowners. Neither the Federal Government nor the State can carry a program of this kind through to completion without the support and assistance of the individual landowners. We cannot overlook some fundamentals in human nature which experience has proved will not be changed. The owners of the land where tree planting is done must feel a personal responsibility in the project, be a party to the general planting procedure, and share the costs. As never before in the history of this country, individuals must learn that their tenure of land involves the responsibility of stewardship, and that there is an obligation upon them to pass their land on to future generations with its fertility unimpaired.

Present legislation seems to be inadequate to conduct a program such as is needed. There should be legislative authority broad enough to include all phases of rural tree planting in the Plains States, and ample authority to include full exercise of cooperative effort between Federal agencies, States, counties, municipalities, individuals, and private institutions. It is my sincere conviction that such a program is essential and that it presents a major opportunity in these areas where tree growing can be successfully accomplished for permanent improvement of agriculture and for human benefit.

The objectives of an agricultural forestry program should aim to maintain and improve agriculture within an important agricultural area, by—

1. Conserving the soil and improving moisture relations.
2. Protecting farm crops, gardens, etc., from critical hot winds.
3. Improving wildlife habitat.
4. Producing wood products, primarily fuel, fence posts, and rough lumber.
5. Protection of people and livestock from climatic extremes and improving living conditions in general.

Any contribution by forestry to these objectives will further a comprehensive Federal program for permanent amelioration of the disastrous effects of floods and droughts.

BASIC SURVEY AND RESEARCH

The future management and use of land and

water must be based, more than in the past, on reliable information. This will require well-planned, fundamental survey and research, and a thorough analysis and interpretation of the data. So far as possible, the investigational activities should be coordinated into a fact-finding program with the sequence that will make each activity most helpful to the others.

Agriculture is environed by many physical and biological conditions and hazards. It relates at the start to the formational composition and profile of the land; to topography—its kind and degree of slope; to climate—its forms of precipitation, and the humidity, temperature, wind velocity, and storms; to soil—its genesis, morphology, fertility, temperature, ability to absorb and conserve moisture, and its run-off, erosivity, and agricultural adaptabilities; to streams—their physical features, gaging, and use; to ground water—its quality, quantity, and accessibility; to native and exotic plant and animal life, as grasses, weeds, shrubs, trees, birds, reptiles, and mammals; and to the many hazards such as floods, drought, and the plant and animal pests and diseases.

The foregoing summary of agricultural relationships will serve to evidence the fact that farm practice is involved in many things that require investigational aid from State and Federal departments, and that such aid is an important and necessary factor in the management and use of land.

The States that do not have accurate maps and other reliable data regarding their climate, geology, soils, waters, wildlife, and the historical record of the development, success, and failure in their agricultural industry are not in a position to establish effective agricultural conservation programs.

The need and importance of research, survey, and experimentation should not be denied because it is obvious that long-time planning for the better future management and use of our basic resources—land and water—must have a factual background.

4. Robert P. Holdsworth

Head, Department of Forestry, Massachusetts State College, Amherst Mass.

If I were to be called upon to select from among the many striking and forceful points made by Dr. Bennett, the one point that I consider to be most striking and forceful, I would find myself in an almost impossible situation because as he has pictured the design of upstream engineering, every feature of it seems equally important and necessary.

I have been bold enough to select the following statement as the basis of my comment.

> Foremost in the mind of the landowner or operator, quite naturally, is the important matter of income. The management of land for flood control or conservation purposes may have beneficial effects both to him and to his neighbor, but such benefits may be easily overshadowed, in the practical sense, when his immediate financial return from the land is threatened. On agricultural lands, therefore, and particularly on croplands and associated pastures and wood lots, the upstream engineer is confronted not alone with problems merely physical. His planning for the control of water on sloping fields and pastures must take into account much more than the physical adaptabilities of the land to certain uses. He must pattern his plan to fit as well into the economy peculiar to the region and to each particular farm or grazing area of the region, whether it consists of cropland or range land or forest. * * *. This will take us upstream not merely to a given county, township, subdrainage, farm, or grazing area, but to a particular field, pasture, or wood lot on that farm or grazing unit, even to particular parts of such fields, pastures, and wood lots.

In other words, Dr. Bennett's program scorns generalities and immediately gets down to cases. It is not in any sense a swivel-chair program that he has outlined. It reaches surely and directly into the obscure corners of fields and woods.

As a forester from the Northeast, I am interested naturally in the role which our forests, looming so large in eastern land economy, will play in our upstream engineering problems. In Massachusetts, for example, practically three-fifths of our State is in forest. Approximately 3 out of every 5 acres bear woodland growth.

Our forests cling to the hillsides where rise the little waters that are so important in the aggregate. The values of these woodlands, their physical values let us say, play a tremendous part in the control of the journey of the raindrop to the sea. The importance of their role in this connection has been established and is not to be doubted. It can be said without much fear of contradiction that there is scarcely a single acre of New England forest that in itself is not within the watershed for one of the tiny streamlets that join to make the runs and rivers.

These forests are important then as physical protection to the land, as a living armor against erosion, but they fulfill another and very vital function in this upstream engineering program. Unlike many of the factors that must be used in controlling little waters, the forests are productive. They are capable of yielding economic returns, they may return a very tangible income at the same time that they are used in regulating the journey of the seaward-moving raindrop. Their use as conservators and controllers of moisture in no way checks their forest productive value. In fact, wise and careful use has a tendency to increase all of the values of the forest, including its water-retentive powers.

A good many decades ago when our forests consisted of the original stands, it is true, as Dr. Bennett has stated, that we had occasional floods, but the movement of earth in those floods was comparatively slight. Those virgin forests have now been cut and the forests which have succeeded them have been cut continuously. Much land has been cleared and cultivated and has again reverted to forest. But it is not forest of the old original composition or quality of soil. Our present Massachusetts forests, for example, are very young. It is believed that they average between 35 and 50 years of age. They are characterized by high percentages of tree species that are not conducive to desirable soil formation from the standpoint of erosion. One of these species is the red oak. The old high forest of Massachusetts with its undisturbed flora and water-absorbing forest floor, has largely been converted to low forest of sprout origin which annually deposits a heavy, shingle-like, and slow-decaying leaf litter upon the surface of the soil. Studies made at the Harvard Forest of many of the cut-over old-field pine areas show that the red oak constitutes 75 percent of the crop trees in all of the plots that were analyzed.

It is significant that in the younger stands studied the white ash which is definitely known as a soil-building tree, had practically equal representation with the red oak, but in the older, untreated stands hardly a dominant stem of the valuable white ash survived.

It is these forests, constantly ill-treated by man, and greater now in area than they have been for many years, that occupy so great a present proportion of our soil. They are of vast importance to that group of men named by Dr. Bennett—the engineer, the forester, the agronomist, the climatologist, the economist, and the sociologist, who in the composite become the "upstream engineer."

The forests, of course, are important because even in their present deteriorated condition they are a principal asset in the upstream control of water and an economic asset to each of our 30,000 Massachusetts farm owners who possess on the average 34 acres each of this woodland.

Under forest management the forest values in upstream engineering will be greatly enhanced because the weed species will be reduced in favor of the more valuable soil-building species. Diseased trees will be removed, the quality and condition of the forest will be raised, low forest will become high forest, and the forest soil will be increased in fertility and water-retentive powers. In short, the present haphazard methods of using the forest, which result in steady and progressive deterioration, will be replaced by systematic silvaculture. Under systematic silvaculture we are able to create the physical forest conditions desired by the upstream engineer, and we also create the forest economic conditions

that make the practice of systematic forest management desirable and profitable to the private owner.

It will be the job of this composite upstream engineer to improve the composition and quality of the upstream forest, even to change its pattern in places so that it will occupy more strategic parts of the terrain. It would be folly to state that all of our forest is ideally situated for the control of stream flow. It will undoubtedly be necessary to establish areas of new forest by plantation methods. In contrast to many of the practices in upstream engineering which will necessarily require costly construction and the expenditure of considerable amounts of money, the development of our upland forests as part of this program will have a tendency to increase their yield and value without appreciable increased expenditures.

In Massachusetts it is the usual thing for forest-management plans to meet generally with very fine response from woodland owners.

It is a fact that the great majority of our 30,000 farm owners annually harvest forest products from their wood lots. A large part of this is in the form of fuel wood. It is also a fact that this valuable material is largely harvested without regard to the silvacultural requirements of the forest from which it is taken, with the result that the quality of the forest and consequently its value in upstream engineering progressively declines. Happily, the exceptions that prove the rule are growing in numbers.

If we could help the owners of this forest land, which so commonly lies astride of our little waters, to exchange their practice of haphazard forest use for silvaculture, we would further our program immensely and do it economically. As Dr. Bennett said, the question of *immediate income* plays a large part in this entire program. In our use of the forest we do not need to incur expense for the owner if we go at the matter in a simple and direct way. Let us say to him, "It is probably a fact that you spend some 10 or 12 or even more days each year in your wood lot, during which time you harvest your fuel supply and remove other forest material for farm use and for sale. It is probable that you use your horse or horses 2 or 3 days and altogether, with the help of your family or your hired help, you do a very appreciable amount of forest work. You are going to expend this amount of labor anyway, entirely apart from any program of forest improvement that we may suggest to you. However, in your methods of extracting your forest material you do very little to favor the future saw timber of high value that is now a young component of your forest. You don't attempt to improve the composition and spacing of the trees in your forest in order to obtain a better stand with maximum growth and crown development on the better trees. It is quite possible that by your method of harvesting your forest products you are progressively deteriorating the soil."

If this man is good natured we may continue to tell him of a number of faults that we think are being committed in his forest practice. We won't be able to make much progress with him until we show him that he can, by using no more labor each year than he is now using, actually improve his forest and increase the yield of forest products if he will adopt some very simple silvacultural practices. In short, he will exchange haphazard for planned and systematic cutting by regard to the elements of forest management. This involves no extra cost to him, no increased expenditure of labor. It merely means that by following systematic cutting for a term of years he will have a clean and thrifty wood lot instead of one that is steadily declining in value.

Naturally, if our upstream-forest owner expresses willingness to follow our suggestions and to cut his forest scientifically and methodically, he is also going to ask us to show him how to do it. He will want our assistance and guidance in accomplishing the ends that we have suggested as being possible. And right there is a weak spot in the program of the forester. Dr.

Bennett has said that this program must be carried to particular parts of particular fields and forests, and in my opinion he is absolutely right.

In order to make the forester's part of this program definitely effective in our region, we must carry forestry into particular parts of particular forests and actually mark particular trees for the owner. And the forester must do an intelligent job of it, too. If he does, he is going to be of great help in furthering upstream engineering. But if he isn't able to get down to cases, if he gives long-distance advice, he will receive very little attention and a great part of our valuable water-retaining forests will continue to deteriorate physically as they have in the past.

In our State we have but one extension forester. This man runs himself ragged trying to meet the calls made upon him, and I think that the same situation holds true in our other northeastern States. There is no question in my mind of the vital importance of the forest in this upstream engineering program and in order to make the program effective we must physically carry it into the woods. To do this we will need more extension foresters. They should be mature, well-seasoned, experienced men. In my opinion they can pay their way. Our experience has been that once offered a real and tangible help the forest owners will cooperate. We need men to establish systematic forestry in particular parts of particular forests in order that our valuable woodland may play its high and effective role in a vitally necessary and forward looking program of upstream engineering.

5. C. Warren Thornthwaite

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In illustrating the deficiencies of essential data for the development of proper methods of upstream soil and water conservation Dr. Bennett referred to a climatic project being operated by the Soil Conservation Service in western Oklahoma. In this survey precipitation records are obtained at 15-minute intervals from 200 rain gages concentrated in three counties and spaced at an average distance of 3½ miles. From these records maps showing the rainfall in each 15-minute period and others showing the accumulated depth of precipitation are made. Over 800 maps were required to chart the rainfall distribution for the month of May 1936. The maps of a rain which occurred in the late afternoon of May 1, together with maps of temperature and wind velocity and direction for the same period, were presented for the conference on two charts in the Soil Conservation Service exhibit.[5]

The storm of May 1 was associated with the passage of a polar front across the area. At 3 p. m. the wind was from the south and southwest and the temperature between 84° F. and 90° F. By 4 p. m. in the northwest corner of the area the wind had shifted to north and the temperature had dropped about 10° F. Thereafter the wind shift line continued to move across the area until shortly after 7 p. m. it pushed off at the southeast corner, at which time the wind was everywhere from the north and the temperature was nearly 30° F. lower than at 3 p. m. The rain commenced in the north central portion of the area at 4:45 p. m. The storm moved southeast and shortly after 7 p. m. had disappeared from the southeast corner of the area. In the series of maps it is possible to trace the migration of the storm and the development and change of the centers of greatest intensity. The precipitation came from the warm, light, moist, tropical air which had been forced up by the invasion of the cold, heavy, dry, polar air from the north. More than 3,500,000,000 cubic feet of water fell on the portion of the Cimarron watershed included in the project.

The studies carried out on this project suggest an entirely new approach to the flood problem. We propose to study the characteristics of com-

[5] These maps are reproduced in color in the *Geographical Review*, January 1937, p. 96.

plete storms, determine their areal extent, their usual migration pattern, their intensity distribution, their total water contribution, and the pattern of the rate of fall. Statistical studies will determine the frequency distribution of rates of fall for storms having various size, shape, and migration characteristics. These facts can be applied directly to other regions of known area, configuration, and cover to determine the probability of fall of precipitation of certain amounts and rates. From these studies the extent of flood hazard can readily be determined.

6. O. S. Fisher

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Conditions early in 1936 in a considerable part of the southern Great Plains were very favorable to wind erosion. Early surveys indicated that while approximately 12 million acres were subject to wind erosion in 1935, only 4½ to 5 million acres were likely to be affected in 1936. This smaller acreage, however, was much drier than in 1935 and there was every indication that wind erosion would be severe with accompanying duststorms and serious damage to land, buildings, health, etc.

To aid in meeting this situation, Congress appropriated $2,000,000 in an act signed by the President on February 29. On March 3 the Regional Advisory Committee on Land Use Practices in the Southern Great Plains met at Dodge City, Kans., and drew up proposed regulations for carrying on the control program. These regulations were approved by the Acting Secretary of Agriculture on March 7, and on March 20 funds for starting control work were in the hands of the various States. At the request of the Governors, allotments were made by the Department to the State agricultural colleges which, in turn, made allotments to county wind erosion committees set up by the Extension Service. Allotments to the States were as follows:

Colorado	$500, 000
Kansas	500, 000
Oklahoma	200, 000
New Mexico	250, 000
Texas	500, 000

The regulations authorized the county committees to make allotments to farmers for wind erosion control work, principally listing, at rates not to exceed 20 cents per acre where the farmer had his own equipment, and at not to exceed 40 cents per acre for work on abandoned land or where the farmer had no equipment. On approval of applications, the committee advanced 60 percent of the grant to the farmer, the remainder being paid on satisfactory proof of performance. State colleges and county committees were limited to 5 percent of total expenditures for supervisory costs, the county committees receiving no salaries and only nominal reimbursement for mileage and subsistence.

Grants were made to 106 counties in the five States. As the drought continued through the spring, acreage subject to wind erosion increased and was finally estimated at 6,500,000 acres.

Summarizing briefly the work done on this project:

1. Total applications of farmers approved for listing, 40,329.
2. Total acreage covered by approved grants, 6,542,921.
3. Total acreage listed, 6,375,752.
4. Total acreage listed on contours, 2,272,330.
5. Total funds spent for tillage, $1,363,318.37.
6. Total administrative expenses, $59,273.16.
7. Balance on hand in State depositories or unallotted, $577,408.47.

This latter amount is available for work in wind erosion control during the coming winter and spring.

Excellent results in soil and water conservation were obtained at a low cost. Borings made following several days of rain in the Texas Panhandle showed moisture penetration on treated land twice the depth of that on untreated land.

Excellent cooperation was given to the Extension Service and county committees by the Soil

Conservation Service, the Resettlement Administration, and other agencies which supplied personnel for the running of contour lines, thus making possible operations on contours on more than one-third of the total acreage treated.

An indication of the willingness of farmers to do work of this kind almost wholly at their own expense is shown by the fact that in New Mexico more than 500,000 acres were listed in 1936 in addition to that financed with the emergency appropriation. The entire contribution of the Extension Service for this work consisted of furnishing technical assistance in running the contour lines.

CHAPTER VII

Control and use of small streams

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INTRODUCTION

WATER is our greatest natural resource. It is as necessary to life as the air we breathe or the food we eat. Under control it becomes this country's greatest asset. Out of control it may become its greatest liability because of its power of erosion and transportation.

In this discussion I wish to treat the subject of the use and control of water in humid and semiarid regions as it occurs in small streams, and its effect on the characteristics of flow of large streams. The term small stream is used here to define any stream that is tributary to a main arterial drainage channel. Under this definition a small stream is not limited by its discharge in second-feet, but rather by its position in the network of collecting channels through which water falling on a drainage area is conveyed to the main streams and thence to the sea.

The control of small streams will determine largely the efficiency of their use, but, conversely, many uses of small streams aid materially in their control. The problem is a complicated one, and its solution requires the unified effort of those working in the fields of biology, geology, and engineering. At the outset it must be recognized that conditions in the East and the West are entirely different, that every stream is a law unto itself, and that the control and use of any stream must be determined by the physical, economic, and land-use conditions pertaining to that area which feeds it.

Precipitation is the source of all run-off, and to a large degree, precipitation characteristics of any region will determine run-off characteristics. In general, east of the one hundredth meridian, the annual precipitation is fairly high, reaching its maximum during the summer months. West of the one hundredth meridian, the major portion of the precipitation occurs during the winter, and accumulates and forms the snow storage which is the principal source of all western streams.

This difference in eastern and western precipitation divides the United States into two distinctly separate regions with respect to use and control of water. In the eastern part of the United States, except for culinary and supplemental irrigation use, water is something to be disposed of. Water-rights do not attach to the body of water, but merely to its presence. The riparian doctrine governs and is based upon ownership of the bank of the stream. In the western part of the United States, the principal use of water is consumptive. The body of the water is actually used and not allowed to pass to lower lands. The doctrine of appropriation governs its use. "First in time is first in right" and beneficial use is the basis and the measure of this right. Out of these two fundamentally different situations in the East and in the West have grown the two key problems in control and use of small streams. In humid regions the problem is disposal of water, and in the semiarid regions it is conservation of water.

USE OF SMALL STREAMS IN HUMID REGIONS

The use that can be made of small streams in any region is determined largely by the physiog-

raphy, climate, soil, land use, and population environment. In humid regions, their use is largely for domestic supply, power, industry, recreation, sewage dilution, ice manufacture, and wildlife, and in some cases, for supplemental irrigation. Of these uses, only those for domestic supply and for supplemental irrigation are consumptive. In the others, water is used and passed on.

The greater the water losses in evaporation, transpiration, or deep seepage, the better the natural regulation and the easier the control. Ordinarily, this is a desirable situation in a humid region, because the principal problem is one of disposal. An exception to this would be during the low-water period of dry years when such losses would seriously interfere with domestic supplies and use of streams for sewage disposal purposes, or supplemental irrigation.

Now let us consider the general uses that are made of small streams. It is universally agreed that domestic use takes precedence over all other uses. Small streams are the principal source of domestic water supplies and controlled stream flow is essential if a shortage of culinary water supplies, such as existed during the drought years of 1930 and 1934, is to be avoided.

Each small stream is a potential source of power with proper control and regulated flow. Reports on rural electrification in the Eastern and Middle Western States show a serious lack of electrical service. In many cases lack of development has been due to the fluctuating character of stream flow. Equalized flow is essential to efficient hydroelectrical development, and any control which will tend to equalize the flow of small streams will increase their potential power capacity.

Proper sanitation requires water with which to dispose of human wastes. The effluent from sewage-treatment plants is discharged into stream channels. Water is necessary to dilute this effluent properly. A low-water flow, at least sufficient to take adequate care of sewage disposal needs, is imperative on every small stream and constitutes an important stream use. Any modification of the characteristics of flow which will decrease the peak and increase the low-water discharge of a stream will increase the utility of the stream for sewage disposal and decrease stream pollution.

Recreation and wildlife have recently assumed a role of great importance until now the common slogan is, "For every community a natural playground." Small streams where fishing,[1] hunting, and camp sites may be developed are essential to such a program. Recreational and wildlife uses cannot be made of intermittent flashy streams; therefore, controlled flow is of primary importance. Flood flows wash out recreation ponds and destroy bird life. Dry stream beds in late summer are not conducive either to desirable plant growth or to the development of camp sites and parking areas. All streams in thickly populated sections, or in sections which are accessible, should be developed for fishing and wildlife and recreational uses. The development of small streams for recreational use automatically improves their characteristics for power and industrial uses, and in some instances for irrigation use. Where the streams are used for domestic purposes, their recreational use must, of course, be limited.

For all of these uses a regulated flow with a minimum daily, monthly, and seasonal variation is desirable. The small consumptive use of water from streams in humid regions makes equalization of flow doubly important, because that water which falls on the earth's surface must either be disposed of or allowed to flow downward to the sea. Fortunately, the aforementioned uses, while not all consumptive, are retarding. Storage and equalizing reservoirs for municipal and power purposes, lakes and ponds for recreation, checks and channel changes to create better conditions for fish life, and ponds and marshes created for propagation and development of bird life all retard run-off and

[1] Silcox, F. A., *Fish Stream Improvement Handbook*, U. S. Department of Agriculture, Forest Service: 1–39, 1936

delay concentration of flow. These structures greatly increase consumptive use of water by native vegetation and cause more water to be taken into ground storage for later release to streams when discharge is less, and when the water table assumes a position higher than the water surface in the stream. Any use which consumes or delays high-water run-off or increases the low-water flow from small streams, improves the regulation, control, and use of large streams.

USE OF SMALL STREAMS IN SEMIARID REGIONS

In the States west of the one hundredth meridian the use of water has an entirely different aspect. In this region, as I have pointed out, its predominating use is consumptive. Agriculture is impossible without the artificial application of water to supply the necessary soil moisture for plant growth. Most of the area in these States is too steep to be utilized for production of crops; this rough mountainous area, however, gathers the precipitation which is the source of the water supply for the valleys below. This mountain-valley relationship makes the fertile but relatively arid valleys dependent upon the moisture from the high-drainage areas. Most of the streams which originate in these mountains are small and relatively short with steep gradients. Little surface storage is possible, and use must be made to conform as nearly as possible to the natural flow of the stream.

The streams of this region are snow fed, with some minor contributions from summer storms. The snow begins accumulating within the high watersheds in October and continues to accumulate without much melting until about the first of April. It is from this accumulated snow storage that the major portion of the water supplies of the Western States comes. In Utah, for example, approximately 80 percent of the run-off from April to September is derived from the areas above 7,000 feet elevation, which constitute only 20 percent of the State's area. Water-producing areas of other Western States are in similar proportion. The agricultural area on which most of this water is used probably does not exceed from 3 to 5 percent of the total land area.

The prosperity and growth of the entire western commonwealth is dependent upon the water production from its mountain streams. Cities and towns with all their improvements and agricultural areas are dependent upon the seasonal water supply. In general, land is plentiful, but water is the limiting factor. Therefore, conservation and the maximum utilization of water, consistent with other natural resources in the West, is the ultimate objective of watershed management and land use, which of necessity includes the control and use of small streams.

In Western United States all streams with the exception of the lower Columbia, Missouri, Colorado, Arkansas, Rio Grande, and Platte Rivers, may be classed as small streams. They are principally snow fed, and their peak flow, which is from 5 to 20 times their low-water flow, occurs during May and early June. The low-water period is usually from July to September, inclusive.

After the demands for domestic use have been met, the supplying of water for irrigation is the most important use of small streams in Western United States. The natural flow of western streams does not coincide with the irrigation demand which usually begins in early April or May. The peak stream flow occurs when the plants require the least water; as the irrigation demand increases, the natural flow decreases, and as a result, agricultural practices are often limited to early maturing crops. Regulation and control of the streams by some means to make the flow more nearly conform to the demand is essential to maximum irrigation use.

In the West, where water is consumptively used, the various uses sometimes conflict. "Conservation of water for beneficial use" is the slogan. Culinary and domestic use are given first preference, with irrigation, power, and industrial uses

following. If the water is not needed for any of these uses, it may be used for recreation, fish culture, or wildlife. Recently, the development of recreational areas, channel changes for fish development, and construction of ponds for wildlife have often seriously interfered with prior rights to water for irrigation and power purposes. The objection to the use of water for these latter purposes would probably never rise in a humid region, but in the West, where water for agricultural purposes is the limiting factor in the development of the commonwealth, any use other than agricultural should be carefully scrutinized before authorization.

Utah offers many typical examples of the use of small streams. A community is located at the mouth of practically every stream that emerges from the mountains. These communities utilize the water of the streams for irrigation, power, or municipal purposes. The entire low-water flow is utilized. Where surface storage is available in the canyon, a reservoir is constructed to store the spring high water and to equalize the flow. If such storage is not available, the spring high water is wasted into the valley below. Where possible, this waste water is used to supply marshes with water and to provide nesting places for wild fowl or ponds for fishing. The construction of ponds for wild fowl and retardation basins and deflector dams for fishing betterments is usually detrimental to irrigation use, when such construction is above the irrigated area. Any structure that will retard high-water flow is beneficial, but structures which retard low-water flow, which increase seepage, evaporation, and transpiration losses and which decrease the net usable irrigation and power supply during the low-water season are detrimental to western commonwealths.

To illustrate some of the problems which may arise from attempts to control small stream flow, I might cite another example from Utah. The Sevier River, which is approximately 200 miles in length, supplies irrigation water for 260,000 acres of land and supports a population of 25,000 persons. The river system has approximately 500,000 acre-feet of surface storage capacity in reservoirs scattered from near the lower end of the system to mountain lakes near the headwaters. The storage reservoirs, most of which are in the lower valleys, are sufficient to equalize the entire flow of the river. They are of no use, however, in the control of the small tributaries, and it is on these tributaries that damaging flood flows are now occurring. Control of the flow from the tributaries by check dams, terrace trenches, retardation basins, and vegetation, which I shall discuss more fully later, will increase the net usable supply of water to the communities at the mouths of these tributaries by reducing the peak flow and improving the late summer flow, but it will decrease the total run-off into the storage reservoirs in the valley. For this reason, two opposing groups of water users have developed: (1) Those who desire control of small streams because of better regulation and greater usable natural flow, and (2) those who oppose it on the grounds of a decreased storable flow.

Native vegetation, fish ponds, and marshes are heavy consumers of water. Infiltration of water into the surface soil increases both evaporation and transpiration opportunity. Delayed run-off decreases the total yield of water from a stream, but it also moves the time of run-off further into the irrigation season so that the flow more nearly coincides with the irrigation demand. The net result, therefore, of delayed run-off on streams where surface storage reservoirs are not available is beneficial. On others, where surface storage reservoirs are available to equalize the flow, the net result, from a standpoint of water yield, is detrimental.

If erosion within the watersheds and damage of valley lands from flood flow are considered, the results favor a controlled flow. In spite of the evident benefits of controlled flow, it must be remembered that in the Western States all water must be appropriated and put to beneficial use. Subsequent appropriators for any

use are not permitted to interfere with the rights of prior appropriators, yet retarded flow increases the supply available to natural-flow rights and this interferes with storage rights because it decreases the storable supply. The use of water for recreation ponds, fish ponds, marshes, and retardation basins decreases the total natural flow and thus the water available for storage. Recently, certain Federal agencies, contemplating the construction of such basins or structures, have seriously considered making application to appropriate water for use in or with such structures to avoid interference with established rights. It is believed that the ultimate result of control is a gain to the commonwealth effected, although there may be a slight loss to the holders of storage rights.

In spite of the present uses to which the waters of small streams are being put in humid and semiarid regions, there still remains within most watersheds the flood flow from precipitation and melting snows as well as the run-off from torrential summer storms which is not being utilized efficiently and which annually causes much damage by eroding surface soil in watersheds, by cutting stream channels deeper, by destroying diversion works and silting reservoirs, and in many instances by covering valuable farm land with rocks and debris. Control of small streams to permit a more efficient use and the prevention of erosion and flood damage is a most urgent need throughout the United States.

CONTROL OF SMALL STREAMS

If the velocity of flowing water is low its carrying capacity is small, but if the velocity increases its carrying capacity increases about as the sixth power of the velocity. Thus by doubling the velocity the carrying capacity of a stream is increased approximately 64 times. If water flowing off steep slopes can be made to move slowly as it does through the soil, and kept from concentrating quickly in the drainage channels, its potential energy can be dissipated and the flow controlled. All measures for control of small streams should be predicated upon maintenance of low velocities and the prevention of quick concentration of flow.

The control of small streams is not alone an engineering problem. Mechanical structures may be necessary for immediate relief or to stabilize the soil, but for permanent control of run-off the biological factors of vegetation and its use must be utilized. If large quantities of water must be handled under controlled conditions, engineering structures will become a part of permanent control. Within some watersheds, establishing a vegetal cover may be impossible because of soil conditions; in such areas where control is desirable, it is necessary that structures constitute the control works. In general, permanent control of small streams will involve both mechanical structures and a program of watershed management which will maintain an effective plant cover. The engineer, therefore, has a definite place in any program of control of small streams, not alone in the design and building of structures, but also in the planning and research phases. It is recognized that there is a serious lack of basic data pertaining to the hydrology of streams, the phenomena of mud flows, meterological conditions of high watershed areas, maximum rate of flow, carrying capacities of channels on steep slopes, and other data needed in design. A program of research to supply such data should be inaugurated immediately.

Small stream control, if effective, must result in a stability between topography, soil, plant cover, and run-off. The delicate balance between forces must be maintained. Of the many factors involved in a small stream-control program, this discussion will consider only the mechanical structures.

The mechanical control of small streams should satisfy three fundamental objectives: (1) Equalize natural flow, (2) stabilize the soil within the disturbed watersheds and along eroded stream channels, thus providing optimum soil conditions for revegetation, and (3) afford protection

against floods before watershed conditions have become stabilized and against normal spring high water under regulated flow.

Because lands adjoining stream channels in the vicinity of cities are valuable, there is a constant urge to encroach upon the natural stream channels, to build bridge piers in the stream, and to construct dams and diversion wiers. Such development requires protection works, and even under controlled conditions, stream-flow characteristics in the United States are such that protective works such as levees, channel lining, retaining walls, deflector dams, and wasteways will always be necessary. They will be less expensive, however, and can be designed with a much smaller factor of safety.

The control of small streams is an essential element in flood-protection work because it means control of large streams which they combine to make. It has been amply demonstrated by the Forest Service, the Soil Conservation Service, and other agencies that the vegetative cover plays an important part in small-stream control, and that without a sufficient cover to retard run-off, mechanical structures have only a temporary existence. Nevertheless, in many cases they are essential and without them revegetation is either long delayed or impossible.

Mechanical structures used in the control of small streams may be grouped into four general classes: (1) Storage reservoirs, (2) soil-stabilizing structures, (3) spreading works, and (4) protective structures.

STORAGE RESERVOIRS

Where sites are available on small streams storage reservoirs offer an excellent means of equalizing the flow. Unless the stream is controlled above the reservoir, it will soon silt up, thus destroying its effectiveness. Unfortunately, few desirable reservoir sites are available within small watersheds. The steep slopes require high dams and yield limited capacity. Where satisfactory reservoir sites are available, dams may be constructed of earth, of earth and rock, of masonry, or of concrete. Because of the serious consequences which follow the break of even a small dam, the design and construction should be based on sound engineering principles, and proper examination of foundation and materials should be made at each site. Rigid specifications and adequate inspection are absolutely essential. The construction of storage dams under emergency relief measures is full of danger, since records show that inadequate engineering and poor supervision and inspection are common. With present available information on materials, foundations, and construction methods, there is no excuse for the failure of a storage dam.

STABILIZING STRUCTURES

Soil-stabilizing structures are effective near the headwaters of eroding channels and wherever gullying has progressed to any extent. It should be kept in mind that soil-stabilizing structures such as check dams, gully head plugs, brush wattles, and trench terraces are needed only on the badly eroded spots within each watershed. These spots are usually small yet from these areas most of the floods on small streams originate. In one watershed where serious floods occurred the area of such spots constituted only 6 percent of the total area.

Check dams.—Where gullies have formed, the banks are unstable and vegetation cannot get a foothold. Concentrated flow in the gullies continues to deepen and widen them. To stabilize the soil, it may be necessary to flatten the stream gradient. This may be accomplished by means of dams placed across the stream channel to raise the bed of the stream. Check dams [2] have been used for many hundreds of years as a temporary measure to check cutting while vegetation was getting started and they should always be considered temporary in any plan of small-stream control. They can be used on

[2] Ramser, C. E., *Brief Instructions on Methods of Gully Control*, U. S. Department of Agriculture, Bureau of Agricultural Engineering (unpublished): 1–35, 1933.

relatively steep slopes, where the dams are placed so that the top of one is about level with the bottom of the next one upstream. Properly designed and constructed check dams are expensive and should be used only where a high cost of control is justified.

Where the gullies have cut through meadows and drained them, check dams may be used as soil-saving dams. In such cases these structures are built to form silt catchment basins and ultimately should be as high as the gully is deep in order to restore the soil level and to maintain the water table at its original height. If the gully is extremely deep, the level of the channel should be raised by steps. This type of check dam is practical only on slopes of low gradient, which are characteristic of mountain meadows.

Check dams used to prevent further cutting or as soil-saving dams may be constructed of loose rock with mortar facing, rubble masonry, wire fence, logs, brush, or concrete. All check dams except those of masonry construction should be relatively low. Designs of check dams prepared by the Bureau of Agricultural Engineering, the Forest Service, and the Soil Conservation Service represent those used most in present practices.

Many check dams have failed perhaps through no fault of the designer. The structures were not always built on the sites for which they were designed, and matters of economy or expediency often caused field modification of the design without regard to safety. In much of the recent emergency construction there seems to have been a desire to see how quickly the structures could be built, and often local materials have been used when they have been entirely unsuited for the job. Too often the structures have been placed on poor foundations and inadequate provision made for anchorage. Wing walls and cut-off walls were too light for the location, and in many instances the backfilling was done with dry dirt improperly compacted. There are many examples of failures of check dams in California, Colorado, Nevada, and Utah and probably in other areas. Recently on the headwaters of the Arkansas River, entire colonies of check dams have been washed out by a single freshet. In practically every failure of a check dam the structure was found to have been built on a silt foundation or had inadequate wing and cut-off walls. It would appear that in many instances the design and construction of check dams used in soil-erosion and flood-control work during the past 2 or 3 years have departed far from sound engineering principles and practices with respect to foundation conditions and the hydrodynamics of flowing water. It is true that properly built check dams are expensive, but whenever built they should serve their purpose and not fail the first time flood run-off occurs.

Gully-head plugs.—Gully-head plugs are structures designed to halt the upstream progress of gullies by reducing the grade at the top to a slope which, when paved or protected, will allow the drainage to pass from the upper to the lower level without further erosion. These structures may be in the form of a drop, chute, or more commonly a rock, brush, or prefabricated metal mat placed at the head of the gully to prevent further cutting. In the design of gully-head plugs, ample waterway should be provided and provision made to prevent the water from washing under or around the structure. Typical designs of gully-head control structures are given in the Handbook of Erosion Control Engineering on the National Forests.[3] These structures are not expensive and when properly built are effective in stopping headward erosion. They should be constructed with adequate wing and cut-off walls to force the water over the structure and to prevent its failure by washing around or under it.

Brush wattles.—Brush wattles [4] are constructed by weaving lengths of brush into continuous

[3] Norcross, F. W., *Handbook of Erosion Control Engineering on the National Forests*, U. S. Forest Service: 1–90, 1936.

[4] Kraebel, C. J., *Erosion Control on Mountain Roads*, U. S. Department of Agriculture, Cir. 280: 1–44, 1936.

mats partially buried on end across the slope to be protected. The wattles are placed on contours and supported on the lower side by stakes or cuttings from living trees. Care must be exercised in the construction because the failure of one wattle serves to overload the one below it. Wattles stabilize the upper layer of soil against downhill movements, form barriers against the downward gullying of the slope during heavy storms, prevent small landslides, and make possible the start of revegetation. Wattling is expensive because of the labor involved and is justified only on fill slopes and on badly gullied steep-side hills.

Trench terraces.—On the extreme headwaters of tributaries where serious erosion is taking place on steep slopes, the most effective mechanical reinforcement of the soil is the trench terrace [5] [6] which serves a twofold purpose: It acts as a miniature storage reservoir, holding in storage the precipitation which falls on its tributary area until it has time to percolate into the soil. The soil thrown up as the bank of the trench terrace, when moistened, makes an excellent seedbed and encourages revegetation. The trench terrace delays run-off and prevents quick concentration of flow. The terrace system of soil stabilization and revegetation has been in use for many years in France, Italy, and Switzerland. A modified form of the terrace system has recently been applied with great success to the steep rugged, badly eroded, drainage areas of the West.

The first terrace trench experiment in the United States was inaugurated by the Intermountain Forest and Range Experiment Station in 1933 in the Davis County watershed in Utah. The mountains in this locality are steep and, in the absence of retardent and retentive material, are conducive to rapid run-off from torrential storms. The parts of the watershed area on which floods originated were denuded and cut up by gullies. These areas were found near the heads of the drainages at elevations approaching 9,000 feet.

The terrace trench system, as developed by the Forest Service on the original experimental area in Utah, consists of a series of zero-grade trenches spaced about 25 feet apart horizontally and designed with a capacity approximately double the expected maximum precipitation falling on the area between terraces during any maximum storm. Each trench is made by pushing the loosened soil down the slope to form the lower bank of a miniature reservoir. To secure satisfactory bond between the filled material and the natural slope, the area occupied by the lower bank is cleared before the fill is placed upon it. After the trenches are roughed out with a tractor or with a team and plow, they are finished with hand tools, the upper cuts being reduced as nearly as possible to the normal gradient of the ground in order that erosion from the scar may be minimized. The loose banks are tamped and compacted, equalizing partitions being constructed across the terrace trench at intervals of from 25 to 30 feet. Such partitions are needed to prevent the overloading of a single trench compartment and the draining of the entire terrace in the event that one section of the terrace might overflow or otherwise fail, because of the burrowing of rodents, trampling of game, or an excessive storm. The equalizing partitions are about 3 inches lower than the lower bank of the terrace. If one compartment of the terrace is overloaded due to concentrated flow from above the overflow runs into adjoining compartments.

Following the completion of the terrace trench system, the entire area was artificially reseeded with range grasses and trees were planted. The vegetal cover adds to the stability of the terrace trench and has been found to be an indispensable part of the erosion- and flood-control program.

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[5] Ringland, A. G., *Notes on Soil Erosion and Reforestation in Italy: Suggestions for American Application*, Aug. 1, 1934. 12 pp. (mimeographed).

[6] Bailey, R. W., Shackling the Mountain Flood, *American Forests* 41: 1–4 (March 1935).

The effectiveness of the terrace trench system on the experimental area was clearly illustrated in July of this year (1936) by the manner in which run-off from a torrential storm was held on the surface of the terraced area until the entire precipitation seeped into the ground. On an adjacent unterraced area which was badly denuded, the run-off was quickly concentrated into a raging flood which did considerable damage to the improved valley lands below. On the unterraced area the precipitation was approximately 1.3 inches, most of which occurred in the first 15 minutes. The run-off rapidly formed a system of rills and gullies and concentrated in a steep drainage channel near the headwaters of the drainage area. Here the concentrated flow raked soil and other debris from the bottom and sides of the channel to form a mud-rock flow 17 feet wide at the base, 26 feet across the top, and 9 feet high. This flow progressed down the canyon, sweeping everything in its path and depositing boulders more than 4 feet in diameter in the channel of the main stream as well as over farm lands.

In contrast, the terraced area adjoining showed a precipitation of 1.15 inches, of which 0.95 occurred in the first 15 minutes of the storm. Nearly all of the precipitation was caught in the terrace trenches and absorbed by the soil within a few hours after the storm. Measurements of water in the terrace trenches immediately after the storm showed an average 6 inches, which was the equivalent over the area of a total of 150,000 cubic feet. This water disappeared from the terraces in about 6 hours. The high water in the drainage channel was negligible. During previous years, before this and other adjacent areas were controlled by the terrace-trench system, storms of approximately the same size caused mud-rock flow which resulted in damage to the fertile valley lands below of more than $1,000,000.

Trench terraces control not only the flow from intense summer storms, but they delay and equalize the flow from accumulated snow cover during the melting season in the spring.

The watershed areas of Utah are covered with a network of snow courses over which seasonal surveys of snow cover are made. The surveys of April 1, 1936, indicated an average snow cover 12 feet deep and 50 percent water. In spite of this heavy snow cover and high water content, no surface run-off from the melting snow on this area was apparent. The terraces held the water from the snow until it seeped into the ground. When the snow cover had entirely melted, there was no water in the terraces. These structures had increased the permeability of the soil so that it absorbed the water as fast as it left the snow cover.

It is believed that the terrace-trench system is the most effective means of controlling run-off and erosion on the headwaters of steep mountain areas, provided the trenches are properly constructed and maintained. They must be designed and constructed to store the maximum precipitation which might fall. Careful maintenance is necessary for the first year or until vegetation and settling has consolidated the banks. This mechanical means of increasing the infiltration of water on steep slopes, although effective, must be considered only as a temporary expedient to stabilize the soil until natural or artificial revegetation has been accomplished. As the vegetal cover forms a mat over the surface, the need for the terrace disappears. The method is expensive and must be limited to areas where high costs are justified. It is applicable only on permeable soils and may prove disastrous if applied on clay soils overlying rock, because the saturation of the soil and the lubrication of the contact between the soil and the rock would likely precipitate landslides. The terrace trench as a soil stabilizer has a definite place in any system of control of small streams on steep eroded slopes, where revegetation is the ultimate objective.

SPREADING WORKS

To prevent concentration of flow, it is often possible to divert the water onto permeable

areas and to dissipate it through seepage into the soil. Such spreading [7] may be possible from small mountain streams onto side hills or benches, as has been practiced in the Colorado Basin, or the diversions may be made at the mouths of the canyons where the water may be spread over alluvial fans or lake terraces. Such spreading has two advantages: (1) It improves native vegetation by increasing the supply of moisture, and (2) it serves to recharge the ground-water basins. Experience in southern California has demonstrated the value of water-spreading to recharge ground-water basins, and the experience on the Navajo Indian Reservation in New Mexico shows its value in improving range conditions and simultaneously checking erosion.

Sound diversion dams and spreading control works are necessary to successful spreading; furthermore, continued effective spreading depends upon clear water. Therefore, spreading works must be used in conjunction with other control methods which eliminate erosion within the watershed above the diverting works. The principal value of spreading works lies in their dissipating the flow through seepage, thus preventing harmful concentration of flow below.

PROTECTIVE STRUCTURES

Protective structures include channel lining, deflector dams, revetments, retaining walls, and catchment basins. They are a necessary part of any control program for the following reasons: (1) They are immediately effective in reducing damage from flood flow, whereas permanent control by stabilizing conditions within the watershed may take many years; and (2) even after control of the watershed area above has been established, control structures are needed to handle normal high-water flow.

In humid regions, protective structures are far more important than in arid regions, principally because there are greater quantities of water to be handled. The high annual precipitation yields high run-off. Storms may occur of such duration that the entire ground storage becomes filled while the rain continues. It must run off. The vegetal cover and soil can take no more and protective structures must pass the flow to the sea with a minimum of damage.

Lined channels to allow high velocities of flow, deflector dams, revetments or retaining walls to prevent cutting of banks and undermining of highways, railroads, and other improvements will be found necessary, and their design and construction should be based on sound engineering and hydraulic principles. Such structures are expensive, but they should be built for permanency and with a high factor of safety.

The steep mountain streams of the Rocky Mountain region present a particularly difficult problem in protection against flood flows. In this region irrigation is necessary and settlements have been established wherever streams emerged from the mountains. The better farming lands are located near or on the alluvial fans built up by these mountain streams. When floods come down the canyons, these lands are inundated and covered with sand, gravel, and boulders. Irrigation ditches and power penstocks are filled with debris, and often buildings and improvements are destroyed.

It is the heavy load of debris carried by these floods, rather than the excessive volume of water, that makes their control difficult and the damage great. These floods do not seem to follow the laws of flowing water, but act more like a thick vicious fluid which does not readily change its direction of flow. A recent mud flow from one Utah canyon moved no faster than a man could walk, yet it pushed mud and boulders for more than a half-mile across the alluvial fan. Up to the present time, catchment basins or barriers have furnished the only protection against such

[7] Lane, D. A., Artificial Groundwater, *Engineering News Record,* 116: 779–780, 1936.

floods. The barrier-control plan,[8] developed by the Bureau of Agricultural Engineering and used on many small streams in Utah, is an artificial system of cone building based on the law of hydrodynamics covering the transporting power of water. The plan is to spread the water as it emerges from the canyon, thereby decreasing its velocity and compelling it to drop its load. The larger debris is deposited almost immediately as the flood spreads out, the finer material settling in a stilling basin above the artificial barrier. The essential features of the barrier system are: (1) The barrier or cross dike, (2) the spillway, (3) the lateral dike, (4) the stilling pool, and (5) temporary drift dam.

The primary consideration in selecting the site of a barrier system is to secure a comparatively broad and even area over which the flood can be spread and upon which the debris can be deposited. It must have sufficient capacity to hold the debris, and the barrier walls must be constructed so they can be raised as the barrier fills up. The embankment must at all times be high enough to prevent overtopping. A freeboard of from 3 to 5 feet is usually desirable.

The barrier and dikes may be built out of whatever material is available at the site of the barrier and they need not be impervious, provided they are stable against both overturning and erosion. An adequate spillway capacity, to take care of the flow of water after the detritus is dropped, is necessary. The spillways may be built of timber and rock or of rock masonry. A stilling pool should be present in front of the spillway to settle out the finer materials, and adequate provision should be made at the bottom of the spillway to prevent scouring.

Although these barriers have been found highly effective in reducing damage to communities and farm lands, they are only a temporary remedy. With each storm they fill up with debris, and the banks must be raised or their effectiveness lost. Because the peculiar characteristics of mud flows and their failure to follow the laws of hydraulics, in many instances, the mud flow has overtopped the walls of the barrier without first fully filling the catchment basin. Ultimately, there is a limit to the height to which these barriers can be built. Once filled, they become a menace because the next flood may overtop the structure and cut out the easily erodable material with which the barrier is filled.

Catchment basins for protection against ordinary flood flows when properly maintained give quick results and play an essential part in any control program on small streams in semiarid regions. These, together with other protective works, are essential to immediate relief; for permanent control, however, such structures are not sufficient without the stabilizing influence of an adequate plant cover within the watershed.

Engineering structures play an important part in any program for control of small streams. Their design and construction should be based upon sound engineering principles. The many failures of structures used in flood control and erosion works during the recent storms lead one to question the value of such structures or to cast reflection upon the engineers for their design and construction. What has been the cause of these failures? Who designed and built these structures that have failed? Is it the fault of the designs? Were the structures built as designed? Were they modified to meet the pocketbook, the materials at hand, or the construction conditions and difficulties? Were these structures built merely to create work or were they built to serve a useful purpose in checking and controlling flood flow?

It would appear that sound engineering has been relegated to the scrap heap in the hurry and bustle to make a showing and to put men to work. Construction has been executed under difficulties. Inadequate planning and inefficient supervision and direction have been para-

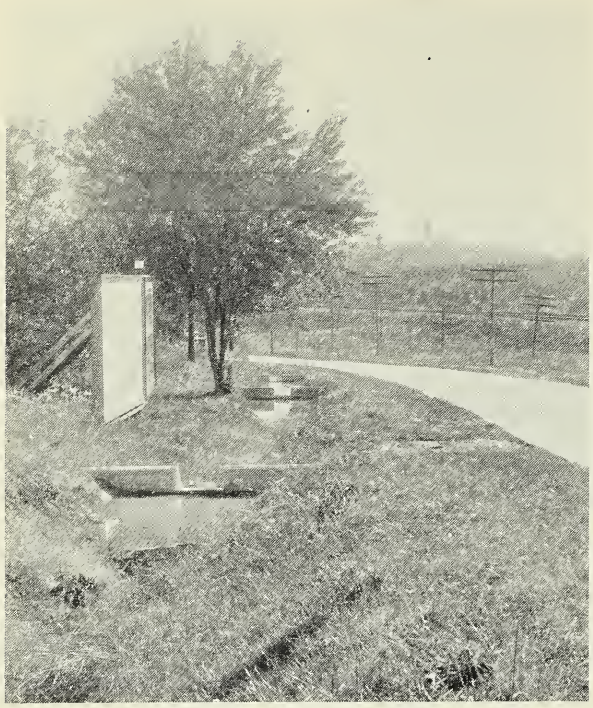
[8] Winsor, L. M., *The Barrier System for Control of Floods in Mountain Streams*, U. S. Department of Agriculture Misc. Pub. 65. 24 pp., 1933.

U. S. Soil Conservation Service photo.

FIGURE 61.—Stream improvement for recreational purposes.

U. S. Soil Conservation Service photo.

FIGURE 62.—A farm pond, designed for gully control, which provides stock water, fish, and a refuge for wildlife.



U. S. Bureau of Agricultural Engineering photo.

Figure 63.—Check dams in highway drainage ditch.

U. S. Bureau of Public Roads photo.

Figure 64.—Small highway bridge designed to create a small reservoir.

U. S. Bureau of Public Roads photo.

Figure 65.—Highway construction designed to provide the dam and spillway of a water-supply and recreational reservoir.

mount. Much of the work has been done with untrained foremen and untrained help. The result has been an unreasonable number of failures. It is probably not the fault of the men but of the system.

The design and construction of control structures is a complicated engineering problem, yet the agencies charged with this work have operated with a limited engineering personnel. Perhaps the forester and the soil conservationist have failed to recognize the importance of sound engineering principles of design and construction in flood control works, but whatever the cause of the present situation, adequate control of small streams is still dependent upon the combined efforts of the forester, the conservationist, and the engineer.

SUMMARY

We have considered the many uses to which the water of small streams may be put. Some of these uses conflict. The most important consideration in one area is water conservation, in another, the safe disposal of water. For maximum use and protection, whether it be in the East or West, controlled and equalized flow is necessary. Such flow can be obtained only through the execution of a coordinated plan of action involving the mechanical structures to stabilize the soil, to delay run-off, or to pass flood flows for temporary and immediate relief, as well as a long-time revegetation program for permanent stabilization of the soil cover. Storage reservoirs, soil stabilizing structures, spreading works, and protective works are all effective under proper conditions, provided they are adequately designed, built, and maintained.

In general, there have been too many failures of structures used in the control of small streams. Apparently too much attention has been given to propaganda and an attempt to make a showing and too little to sound engineering design and construction. There seems to be a lack of engineering personnel in the organizations doing most of the work on control of small streams as well as a serious lack of basic data upon which to predicate proper designs. Construction under the emergency program has not been conducive to the best results for this type of work. The control of small streams is vital to our national welfare, and engineering structures play an important part in that control. The engineering profession should recognize the importance of the problem and take an active part in planning for its solution and it should insist that all control structures be based on sound engineering design and built under rigid specifications and careful inspection.

DISCUSSION

1. Edward R. Jones

Chairman, Department of Agricultural Engineering, University of Wisconsin, Madison, Wis.

Dean Clyde has given you a clear picture of the upstream engineering problems of the Nation as a whole. I shall attempt to present a close-up view of conditions in the five States of the upper Mississippi Valley, Wisconsin, Minnesota, Iowa, Missouri, and Illinois, which, according to Regional Conservator Uhland, contain 63.6 percent of the grade A farm land of the United States.

Upstream engineering of the past has limited itself largely to the construction of power dams, bridges for streams and rivers, and artificial drains for agricultural lands. Other activities, notably erosion control and water conservation, are now looming large on the horizon. I propose to point out some of the limitations of the old activities, to enumerate some of these newer ones, and to stress the interrelation of erosion control to all of them, going only so far into the details of some of the controversial phases of erosion control as time permits.

POWERLESS POWER DAMS

While there are a few sites where a dam of sufficient head can be constructed at a reasonable cost; where the flowage will not cause excessive damage to valuable agricultural lands;

where the dry-weather flow is sufficient to furnish a continuity of power; where the dam site is near enough to the farmhouse to keep transmission losses within reason; where a safe spillway can be provided to protect the dam from the dangers of a washout; and where the drainage area is in such condition that the pond will not fill up with silt before the installation has paid for itself—while some are thus favored by nature, most of the sites in the upper Mississippi Valley where the farmer may think he has a valuable mine of white gold, lack one or more of these very necessary requirements. Most of these projects have a short stave that limits their profit to less than that of an isolated battery, or a wind-electric plant. It is just as much a part of good upstream engineering to refuse to design a plant on a site that has less than a 50–50 chance for economic success, as it is to supply the correct design for the 1 plant in 10 that, after thorough examination, has the physical and economic characteristics that make for success.

Mountain streams with a steady dry-weather flow of siltless water and plenty of fall can develop power economically. There, the problem is to find a use or market for the power within a distance that does not entail a prohibitive transmission loss. Streams in agricultural lands find a ready use for their power on short distances, but the power that can be developed is generally too small to be profitable. Between the two horns of this dilemma easily 90 percent of the projects, which at first glance may promise well, must fall into the discard because they cannot stand up under the acid test.

The owners of the 1,100 power dams in Wisconsin, some of them municipalities, have combed the rivers so thoroughly for profitable sites that there are not many left for development. Each year, old dams and wheels that have run grist mills for 70 years are abandoned because the ponds have silted full. The big utility companies are building steam-generating plants on the shore of Lake Michigan where soft coal is cheap. Diesel-driven generators are using cheap oil fuel where coal is expensive. All this, because the cream of the waterpower in agricultural counties is already harnessed.

Picturesque water wheels on small streams may seem sentimentally sensible, but most of them are economically unsound.

CULVERTS THAT CAUSE GULLIES

In spite of the splendid progress of highway engineering in the last 20 years, highway culverts are being constructed with too little consideration for the accelerated gully erosion caused by them. The culvert bottom is usually put 2 or 3 feet below the bottom of the watercourse above it. That causes a waterfall from the farmer's field to the road ditch, which starts a gully up the watercourse. In all of these cases, and there are hundreds of them, the highway authorities should provide a drop inlet at the upper end of the culvert. I am glad to say that since 1933 highway engineers have recognized the necessity of such structures, and some Wisconsin counties have adopted them as standard practice.

Suppose a gully head below a culvert is advancing rapidly toward the highway culvert. Perhaps it has reached a point at which a soil-saving dam could be constructed conveniently to save the threatened culvert for the county, and the intermediate land for the farmer. Perhaps the farmer offers to make the earth fill for the dam if the county will put in the drop-inlet spillway through the dam. In too many cases counties have had to spend $2,000 for a new bridge a year or two later, just because they refused to spend $500 for a preventive cooperative enterprise at the right time. In other cases counties have cooperated in these control structures to the mutual benefit of themselves and the landowners.

PRESERVATION OF GLACIAL LAKES

Generally, glacial lakes are getting shallower, because of (1) the deposition of silt and vege-

table matter in their beds and (2) the natural channel erosion that is lowering their outlets.

The deposition of silt can be remedied by a weir spillway dam on the stream at the inlet of the lake, to make a settling basin of the marsh adjacent to the stream. The maintenance of the present, or even a higher, lake level can be accomplished by an erosion-proof weir spillway dam at the outlet of the lake. Reinforced concrete with ample footings is the most permanent and probably the cheapest material for these dams. The rights of riparians are involved. In many cases, the natural channel erosion at the outlet has lowered the lake and dried up the adjacent marshland to an extent that the marsh is used for agriculture. Other marshes are undergoing a similar natural development. It seems reasonable to assume that a landowner is entitled to the improvements that natural processes may make in his land. The prevention of this natural process by an artificial dam is a measurable agricultural damage to the riparian. Likewise the creation of a silting basin above the lake, making the marsh wetter, may impair its agricultural value temporarily. Compensation for such damages, where the individual surrenders certain rights to promote the public welfare, is one of the items to be considered in the cost of construction.

A survey of lakes, particularly in Wisconsin, Michigan, and Minnesota, is recommended to determine which should be preserved and which should be allowed to dry up, in the light of the cost of the control works and the public benefit that would result therefrom.

CLASSIFICATION OF MARSHES

Aside from the marshes adjacent to lakes, there are in glacial regions many marshes of from 100 to 3,000 acres that are now too dry for ducks but too wet for corn. True, some of them are drying up gradually for the same reason that lakes are drying up. This natural development may or may not be favorable to the public. Without doubt, some of the marshes should be improved for agriculture, while others should be made wetter and preserved as wildlife sanctuaries.

Timbered swamps present another problem. Some drainage does improve the rate and quality of timber growth, particularly that of the younger trees and sprouts. For example, in the Three Lakes drainage district in Oneida County, Wis., it was found that black spruce seedlings near the ditches grew to a greater height and diameter in the 12 years following the drainage of the swamp than had the parent trees on the same swamp in the preceding 70 years. The Swedish Government is giving its swamps partial drainage as a state policy to promote forest growth.

It is recommended that a survey be made of about 2,000,000 acres of Wisconsin marshes to divide them into two classes: (1) Those that should be kept for wildlife sanctuaries, with a dam if necessary for a higher ground-water table; and (2) those that should be developed for agriculture or forestry. Each area would be made to serve the State better than if it is allowed to remain in its present twilight zone of doubtful destiny and value, somewhere between something and nothing.

The strongest argument that can be advanced for drainage and cultivation of small marshes on upland farms is that it makes possible the raising of the necessary corn on these level erosion-proof lands and the releasing of upland to such erosion-resisting crops as alfalfa. It is estimated that there are 20,000 farms in Wisconsin on which an average of 5 acres of lowland pasture is available for tile drainage as an effective erosion control measure.

COMPENSATION TO RIPARIANS

Where the water table is raised on a marsh or in a lake by a dam constructed for the benefit of the public, or where a marsh is assigned to perpetuity as a wildlife sanctuary, the riparian or owner may be compensated by either, (1) purchase of the overflowed or damaged land

(2) cash payment for the damage, or (3) some other form of compensation.

Purchase of the land even at so low a rate as $5 an acre would involve a considerable public expense. Determination of damage is a complicated and uncertain matter. The third alternate seems more feasible. Let the landowner, for a period of 20 years following the dedication of his wet land to a public use, retain the right to get his necessary supply of fuel or marsh grass from the wet area, and even to exercise exclusive hunting rights on it. During that period, let the land be tax exempt, but, at the end of the period, the land title would revert automatically to the State. This would require legislation, but would give the landowner a considerable compensation, and afford him ample time in which to adjust his farming operations, yet would not require a burdensome outlay of cash on the part of the State to become the ultimate owner of the land in question.

IRRIGATION IN HUMID REGIONS

Almost every year there is a dry period during the summer when crops and pastures suffer from drought. The severe drought of the last 4 years has driven over 300 Wisconsin potato and truck growers to irrigate as large an area as their water supply and facilities permitted—some as much as 100 acres.

Deep wells have furnished the water for most of the small areas, but shallow-driven wells or pits dredged below the water table, are feasible in some places. For larger areas, the water supply has come from a river or lake near the land. This raises the question of water rights between the irrigator and the downstream riparians who are deprived of the water. Legislation on this point may be necessary. Private storage of surface water in the spring or community reservoirs for serving a larger area are possibilities in some places.

Steep permanent pastures can be irrigated from level terraces. Such a terrace with two to one slopes, and with the bottom of the terrace reservoir 3 feet below the top of the terrace ridge, can store 20 cubic feet of run-off for each linear foot. Inch pipes permanently installed at intervals through the ridge to empty the terrace in about 48 hours after the rain, and furrows to distribute the water laterally, irrigate the land on the lower side of the terrace. This practice both reduces erosion and conserves the run-off for irrigation.

WATERLESS PONDS

The drought of the last 3 or 4 years has brought forth much loose talk about the benefits that would accrue from farm ponds of 5 or 10 acres created by damming a watercourse to trap and hold the early spring run-off. Generally, they neglect the spillway or underestimate the cost of constructing such dams with safe spillways; they ignore the danger of a broken dam, dumping its pondage on the land below; and they forget that an otherwise perfect dam on porous soils will have lost all of its water before the drought comes. This month, I saw too many dry lakes to have much faith in the storage capacity of artificial ponds on high land. As a means of slowing down the run-off and increasing absorption, these upland ponds render good service, but, for a visible supply of surface water in a dry season, their value approaches zero. They will have water in them all right during a wet season when the farmer wants his land dry, but they will be noticeably dry during the drought, and they will have spoiled the land for any other use in the meantime. Let us spend our effort improving the storage in lakes, and on large well selected lowland sites, but let us not go contrary to nature by trying to build small upland ponds in questionable places, for any purpose other than to increase absorption. Eight hundred ponds back of as many soil-saving dams in Wisconsin stand full of water after each run-off. Yet they are empty a week afterward from absorption alone. They are strictly not dry-weather ponds. They are wet-weather ponds, and that is what we want them to be.

EROSION CONTROL

Erosion control contributes both to the private gain of the landowner, and to the benefit of the State. It must reckon both with sheet erosion from cultivated fields, and with gully erosion in valley bottoms. Both forms of erosion are reduced by increasing the absorption, reducing the run-off, and providing erosion-proof spillways for the portion of the run-off that is inevitable.

The public is concerned with the damage done to streams and highways by the deposition of silt and debris. It is also in the public interest to maintain a prosperous, permanent countryside. To the landowner, erosion control may cost extra effort temporarily, but the permanent farm income should be increased thereby.

Good practice requires: (1) The maintenance of the forests on the upper slopes of the watershed, their protection, and fencing against pasturing; (2) alfalfa for hay or blue grass for permanent pasture as the predominating crop on lands with more than a 12 percent slope; (3) broad-base, low-gradient terraces on lands with slopes from 4 to 12 percent to carry the run-off slowly across the slope; (4) terrace outlets, sodded or with the gradient reduced by check dams, to receive the discharge from the terraces and carry it safely down the slope; (5) limiting the cultivated crops on steep lands to narrow contour strips separated from each other by wider strips of grass; (6) all cultivation necessary on sloping lands to be on the contour; (7) permanent, wide strips of sod in ravine bottoms; (8) avoiding excessive grazing on steep lands; (9) any other practices, or crop selections, or rotation that will save soil from erosion; and (10) engineering structures to stop big gullies from backing up into a watershed from below, thus undermining all of the preventive practices on the farms themselves. The State can afford to offer subsidies to induce such practices and to build such structures. Mr. Bennett has told you of the ravages of soil erosion, and the noble efforts that his splendid organization is making to combat the further destruction of our soils. I am glad to be a cooperator in that organization.

FOREST OR GRASS?

The forest on the steeper slopes at the head of watersheds and the tops of ridges keeps a loose litter on the surface of the ground that is the best material we know of to increase the absorption of water and to reduce the run-off. The forest should be protected by fences against pasturing, because a pastured wood lot is not a permanent forest, and it isn't much good for pasture. Keep the forests to reduce run-off, but remember that forest slopes are not so good as sod for resisting the violence of concentrated run-off from the cleared lands above them. That is why gullies have cut down to the solid rock through forest slopes where they were asked to carry the concentrated run-off from the cleared land on top of the ridge. That is why we plant sod, not trees, in a gully bottom, to give it a buckskin cover that will protect the surface from the inevitable run-off. That is why we look for a sodded permanent pasture for a terrace outlet, and if one is not available we fertilize and seed to blue grass a strip about 2 rods wide transversely level and longitudinally extending up and down the slope. Protect it from run-off by surrounding it with a low diversion dam for about 2 years while the sod is getting tough; then construct the terraces to discharge into this outlet. I have too much respect for trees to plant them in the wrong place. In a terrace outlet, sod is the smoothest, toughest, and cheapest surface we can get.

Shoestring gullies 2 or 3 feet deep can be stopped by sod-bag dams. Fill gunny sacks with green sod, and lay the sacks about 4 feet apart tightly across the gully. With enough moisture, the grass will grow out through the burlap taking a firm root in the bottom and sides. Water is ponded and silt accumulates between the sacks until eventually the sod spreads over the entire gully bottom.

Gully heads 5 or 6 feet deep in watersheds of

10 acres or less can be healed over by sloping the lip to a 12 percent slope and sodding it by hand. Chicken wire pinned over the sod holds it in place against moderate floods until the sod has taken root, when the wire may be removed. If a sod ever breaks, replace it immediately, because the secret of the safety of the sod lies in absence of any overfall whatsoever. Its surface must be smooth.

THE MYTH OF THE POROUS DAM

I must take exception to the confidence that Dean Clyde and Mr. Ramser place in dams of brush, wire, or loose rock for stopping gullies. Such porous dams have a place as wing dams anchored firmly at an angle at the foot of an eroding stream bank to deflect the current away from the bank and cause silting back of the dam. Note that such wing dams do not cause an overfall, but are merely deflectors. But in a gully bottom, they do cause an overfall, and falling water washes away soil and undermines the structure. Give such a dam a brush mat to bear the impact, and the falling water will undermine that. Out goes the dam. Or, if the porous dam becomes nonporous by the silting of the interstices, the overfall is still there to wash out a hole below the dam which will eventually undermine it.

They tell us to put woven wire dams across gullies, with posts every 4 feet, and the ends of the dam anchored well into each bank. Such dams will cause silting above them, but every inch of accumulated silt above the dam develops an inch of overfall below the dam. That overfall, as it grows, chisels out a hole below the dam. Out goes the dam, taking with it the silt of 10 years of accumulation, and the gully is right back where it was.

SOIL-SAVING DAMS THAT LAST

Be it a check dam to stabilize the gradient, or a soil-saving dam to drown the head of an active gully, an erosion-control dam must have these five requirements:

1. Made of material that will not decay.
2. Watertight, both through it and around it.
3. A spillway of ample capacity.
4. An erosion-proof apron to bear the impact of the overfall.
5. A stable gradient below the structure.

Sod-bag dams, close enough together, meet all of these requirements, and that is why they succeed. In the bigger gullies, for permanent material we must depend upon a mass of well-tamped earth for a dam, and reinforced concrete or masonry for a spillway and tail protection, using established hydraulic and structural formulas to make the discharge capacity and strength exceed the requirements by a safe margin. Insist on the best of materials and workmanship, because these structures are built only where everything else would fail, and they must last forever. The purpose is to concentrate the inevitable run-off at a convenient point, and to drop it down safely to a lower level. The principle is to pond the water in the head of the gully to kill the overfall at the active lip. The head contemplated for maximum flow over the spillway is from 2 to 8 feet, depending on the size of the spillway, and the earth dam must be at least a foot higher than that. We have notch spillways for small areas with low heads; head spillways for large areas with low heads; and drop inlet culverts for large or small areas with high heads. The smallest drop inlet we have in Wisconsin is 2 feet by 2 feet; the largest is a twin 8 feet by 8 feet; and the highest vertical drop through one structure is 43 feet. The run-off expectancy, sometimes found to be 3 inches per hour, is based on Ramser's formula.

ECONOMY IN GOOD STRUCTURES

Not all gullies are entitled to a soil-saving dam. If the gully has begun to send branches 10 to 40 feet deep up the steep slopes at the sides or head of the valley, an adequate structure would cost more than the benefits justify. There, plant trees extra thick. Half of them may tumble into the ditch as the banks cave in, but the other half

will survive and be worth something by the time the gully has stabilized itself by reaching the edge of the watershed. You cannot afford to spend money sloping banks for tree planting. I have seen a splendid stand of black locusts, growing to a height of 12 feet in 1 year in southern Illinois where the banks had been sloped before planting. But, on what I estimated to be 1 acre, I counted 52 woven-wire dams, built to hold the earth in the partly filled gullies. Those dams cost $10 apiece, making the total cost of sloping and damming over $750 an acre. Such expenditures as that in the name of erosion control are going to bring the work into disrepute.

On the other hand, if we can stop a gully 20 feet deep that is entering the comparatively level bottom of a 300-acre valley, we are willing to spend a thousand dollars on a half acre that offers a good site for an everlasting soil-saving dam, because that dam is protecting from the backlash of an advancing gully every one of those 300 acres at a cost of only $3 an acre. The one is an attempt to reclaim the land after it has been ruined. The other is to stop the main gully before the damage is done.

Our farmers have some objections to terraces as they are now built. I believe we can improve both the design and construction methods of terracing so as to remove present objections, but the time allowed for this paper is too short to enter a discussion of that point.

2. Abel Wolman

Chairman, Water Resources Committee, National Resources Committee, Washington, D. C.

The paper by Dean Clyde may be divided into three phases: An exposition of the nature of small streams in humid as distinct from those in semiarid regions; an analysis of various forms of control of small streams; and a discussion of the field measures so far undertaken to put these controls into effect. The paper is exceedingly valuable on all three points, because the author treats the material realistically rather than romantically.

For purposes of discussion, I am sure the author will grant me the privilege of summarizing briefly, largely in his own words, the major conclusions which he reaches on all of the three points noted above. Perhaps the most important of these observations may be listed as follows:

1. Difference in precipitation divides the United States into two distinctly separate regions with respect to use and control of water. In the eastern part of the United States, water is something to be disposed of. In the western part the principal use of water is consumptive.

2. Man can do little about the climate, the geological structure, or the topography, but he can materially change the soil and vegetal cover. Changes in these two important factors will materially affect the watershed losses and through them the run-off characteristics.

3. Small streams have flow characteristics similar to the large streams to which they contribute. Small streams differ from large streams if at all only by arbitrary definition.

4. The present discusser takes the liberty, therefore, of pointing out that upstream engineering, as distinct from downstream engineering, has no meaning. If the term is intended merely to concentrate attention upon one phase of stream engineering, the term may be valid, but it certainly tends to create erroneous conceptions in the minds of the public. Engineering does not stop or change when it moves from downstream to upstream or in the reverse direction. Stream engineering of whatever character should and has taken into account all portions of the stream regimen. What weight should be given to individual portions of such activities still remains to be quantitatively determined in each instance.

5. Whether in the East or in the West, conservation and the maximum utilization of water, consistent with other natural resources, is the ultimate objective of watershed management and land use. Of necessity, this includes the control and use of small streams.

6. In the small streams in western United States, next to domestic use, irrigation is the most important use. On most of these small streams, the low-water period coincides with the maximum irrigation demand. Through adequate control measures to equalize and delay the run-off on small western streams, the net usable supply of irrigation water may be increased.

7. The various uses of water sometimes conflict. Conservation of water for beneficial use sometimes means that the development of recreational areas, channel changes for fish development, and construction of ponds for wildlife seriously interfere with prior rights for water for irrigation and power purposes. This is particularly true when the construction of such undertakings is above the irrigated area.

8. For this reason two opposing groups are beginning to develop:

(*a*) Those who desire control of small streams because of better regulation, and

(*b*) Those who oppose it on the grounds of decreased storable flow.

9. Native vegetation, fish ponds, and marshes are heavy consumers of water. The net result, therefore, of delayed run-off on streams where surface storage reservoirs are not available is beneficial. Where surface storage reservoirs are available to equalize the flow the net result from the standpoint of water yield is detrimental.

This conflict in ultimate purpose cannot be reconciled by overemphasizing one form of control over another at different decades, but only by measuring quantitatively the relative advantages of each and controlling the use of water in a drainage basin solely upon the results of detailed studies of the basin itself.

10. Control of small streams to permit a more effective use and the prevention of erosion and flood damage is an urgent need throughout the United States. Such small-stream control, if effective, must result in a stability between topography, soil, plant cover, and run-off.

11. The construction of storage dams under emergency relief measures is full of danger, as records show that inadequate engineering and poor supervision and inspection are common. There is no excuse for the failure of a storage dam, yet many dams built during the last few years have failed.

12. Check dams must be considered temporary in any plan of small stream control and only where a high cost of control is justified. In much of the recent emergency construction, there seems to have been a desire to see how cheaply the structure could be built rather than how well it may be built. There are many examples of failure of check dams in California, Nevada, and Utah and probably in other areas. Recently on the headwaters of the Arkansas entire colonies of check dams have been washed out by a single freshet. It would appear that the design and construction of check dams used in soil-erosion and flood-control work during the past 2 or 3 years has departed far from sound engineering principles and practices with respect to foundation conditions and the hydrodynamics of flowing water.

13. The advantages and deficiences of gully-head plugs, brush wattles, trench terraces, and spreading works are discussed.

14. Dean Clyde raises the very important question as to whether important mechanical structures for the control of small streams were built solely to create work or were built to serve a useful purpose in controlling and checking flood flows. He reports that the agencies charged with this work have too frequently operated with a limited engineering personnel and that many of the important agencies responsible for this work have had experts in all the fields of endeavor excepting in that field charged with the design or construction of engineering works.

15. This conference cannot pass by lightly the author's general conclusion that "It would appear that sound engineering has been relegated to the scrap heap in the hurry and bustle to make a showing and to put men to work." "In general, there have been too many failures

of structures used in the control of small streams. Apparently too much attention has been given to propaganda and an attempt to make a showing and too little to sound engineering design and construction." "It is time that control structures based on sound engineering design, rigid specifications, and careful inspection replace the slipshod methods now being practiced under the present emergency-work program."

16. It is obvious from the above summary of Dean Clyde's paper that little may be justifiably added in the form of discussion. No one may take issue with his statement of sound engineering principles and practice and of the multiple use aspect of small streams. If this conference does nothing more than make clear that upstream engineering has no significant differences from downstream engineering, that as one moves from one part of a stream to another one cannot discard the criteria of sound engineering principles and practices, and that romanticism must give way to realism in the evaluation of practices on either up or down stream areas, then it will have accomplished its purpose.

The planning and reconciliation of uses and methods of control on streams are difficult problems and do not lend themselves to undue simplification, without serious risk to the welfare and economy of the Nation.

Half truths should be eliminated from the program of stream control, whether large or small streams are under consideration. Quantitative evaluation and substantiation should be the bedrock of promise, where promise is to be translated into fulfillment.

Lay and scientific literature is beginning to be filled with predictions, which some of us at least believe are going to be difficult of accomplishment. A recent reviewer, for example, asks: "Of what good are drastic flood-control measures unless erosion, which leads to floods, is checked in that particular watershed?" To the man who runs and reads or to the man who just runs the inquiry stated above sounds perfectly logical. But it is packed with half truths. Erosion does not lead to floods; not every flood-detention reservoir has been or will be filled with silt. Erosion control, important of itself, is not the panacea for all evil in the water-resources field.

Elsewhere, an author makes the statement: "Promotion of infiltration is the basis of constructive action; first, because measures that promote infiltration at the same time help to prevent erosion, and second, because ground storage is our most important source of water supply." The question may properly be raised, "is ground storage the most important source of water supply?" The answer depends upon geography, geology, topography, and that frequently forgotten element of rainfall.

When we speak of the influence on river flow of "thousands of marshes, pools, ponds, reservoirs, lakes, creeks, and small headwater streams, combined with agricultural processes that retard run-off and promote infiltration simultaneously throughout the entire headwater area" we should at the same time make clear to the lay and scientific reader that these effects are susceptible to quantitative measurement, that they are dependent upon initial rainfall, evaporation, transpiration, ultimate run-off, frequency distribution of rainfall, and competitive uses of water. Without such evaluation, the control of streams, up or down, goes into the realm of emotional romanticism. When that happens, engineering principles and practices must be thrown overboard and when that occurs disaster must soon follow.

Dean Clyde's paper makes quite clear not only the risks involved in the control and use of small streams, but the important benefits to be derived when such control and use follow orthodox principles of engineering practice. Revision of emphasis in this field may be highly desirable, but it should have its origin in logical engineering approach.

As Mr. Saville and Dr. Bowman pointed out in clear-cut terms: "Erosion potential and vegetation potential must be measured and not

guessed at" and "watersheds cannot be broken apart" and handled as patchwork.

It is true that the public must be taught that soil conservation and reforestation must be carried forward regularly in order to recover our natural land and water heritage, but it is emphatically untrue that a terrace on every farm or a tree on every shed will eliminate floods, will change climate, will produce mysterious underground rivers or other much-desired miracles.

The case for soil conservation and reforestation is so good of itself that one must naturally wonder why it should be ruined on the rocks of overstatement, overpromise, or undervaluation of scientific principles.

CHAPTER VIII

Special aspects of application

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A SURVEY OF EFFECTIVENESS OF DAMS OF THE SOIL CONSERVATION SERVICE

By the Soil Conservation Service

As Part of its soil-conservation operations throughout the country during the last 3 years, the Soil Conservation Service has installed or supervised the installation of 289,320 permanent dams for the control or storage of surface waters. These structures range in size from small stabilization dams 1 or 2 feet feet high to large storage dams with a height of about 20 feet.

Surveys recently completed by the Service show that only 0.42 percent of these permanent structures have failed completely under the stress of heavy rains. An additional 489 have been temporarily disabled, but were easily and inexpensively repaired. The percentage of failure, either complete or partial, was therefore only slightly less than six-tenths of 1 percent.

Included in the total number of permanent structures were 28,937 major dams designed either for water diversion or storage purposes. According to the survey, only 0.08 percent of these larger developments have failed completely, and only 0.47 percent have been damaged. Smaller permanent structures intended to provide supplementary protection for grassed waterways, terrace outlets, and similar channels for the conduct of erosive run-off water, and for the stabilization of small gullies, total 260,383. Of this number, only 0.46 percent failed completely and only 0.13 percent were damaged.

This record of efficient dam construction is regarded by the Service as a tangible measure of the possibilities inherent in upstream engineering operations. The structures involved were designed by agricultural engineers attached to field offices of the Service. C. C. C. enrollees and relief labor, under the direction of these engineers, were employed in their construction.

In the arid Plains country, the larger water-impounding dams have proved particularly beneficial in alleviating intermittent water shortages. Farm reservoirs formed by them provide water for livestock and make flood irrigation possible.

In several instances, these larger water-retention dams have proved beneficial in augmenting municipal water supplies, either by seepage through gravel beds into municipal wells and reservoirs or by direct contribution. In 1934, for example, the Soil Conservation Service built a timber crib dam with a storage capacity of approximately 100 acre-feet on the Wild Rice River near Fargo, N. Dak. During 1936, a rubble masonry dam with a potential storage capacity of 380 acre-feet was constructed on the Red River, 15 miles upstream from Fargo, and an 8-foot rubble masonry dam on the Red River immediately above Fargo, designed to store approximately 400 acre-feet of water, is now under construction. Together, these dams will store 880 acre-feet of water for use by the city of Fargo, should its present water storage system prove inadequate during drought periods. During the last summer, preparations were being made to draw from these reservoirs because the Fargo water supply was practically exhausted. The critical conditions which made this neces-

sary can be explained somewhat in the records of the Red River, which is reported to have had no flow at Fargo on 584 days between July 25, 1932, to June 14, 1936.

In 1935 a rubble masonry dam was constructed in the Cheyenne River within the city limits of Valley City, N. Dak., a town of approximately 6,000 population. During the summer of 1936, the city exhausted its own supply of water and that impounded by a nearby Soil Conservation Service dam. Early in September the city was preparing to draw water from a second reservoir constructed by the Service, 15 miles upstream.

A rubble masonry dam built by the Soil Conservation Service in 1935 in the James River, near LaMoure, N. Dak., has backed water upstream for a distance of 11 miles. For its water supply, LaMoure depends upon a large well which taps a gravel vein fed from the reservoir 11 miles above the dam. City officials reported that throughout the summer of 1936, when drouth conditions were as severe as any in the history of the area, their well had an average of 6 feet more water in it than in previous years before the construction of the dam. Subdrainage through the gravel beds from the reservoir is the only reasonable explanation of the increased supply of well water during this exceptionally dry season.

Dams used to spread water in the semiarid Southwest, and in some sections of the Great Plains have shown exceptional results. These water-spreading dams are used across recently entrenched drainages, located in the rather flat valleys found in the Southwest. The gullies or arroyos, as they are termed locally, did not exist prior to the settlement of the area by the white man, with his herds of cattle.

Overgrazing has increased the amount of water lost in run-off, and the once well-grassed, flat valleys have been severely gullied by the rapid movement of concentrated water over bare, unprotected land. Such gullies are often from 10 to 20 feet or more in depth and subject to constant lateral and headward expansion. Probably one of the most serious aspects of this type of gullying is the lowering of the ground-water table in the valley itself, thus depriving vegetation of the scant near-surface water upon which it was originally able to survive.

The water-spreading dams are designed to divert water over a large area of land. Instead of providing a spillway over the dam, the excess water is carried around the ends of the dam and spread by a system of water-training dikes. Ordinarily, most of this water is absorbed by the soil for the use of vegetation, but occasionally some small part of it re-enters the gully. In this latter case, it is again impounded and used by water-spreading structures farther down the stream. In effect, this is a system of practical flood irrigation.

At Mexican Springs, N. Mex., several earth dams were built by the Soil Conservation Service to conserve and spread rain water. In June 1935 studies were started to determine the effect of flood irrigation on the native range grasses. Following the summer rains, grasses on six flood-irrigated test plots showed an increase of 49.4 percent in density; the volume of grass had increased 10 times.

The experience of engineers of the Soil Conservation Service during the last 3 years in constructing over 1¼ million temporary and permanent dams of all sizes and types, under all physical and climatic conditions, has tended to crystallize thought in regard to the functional classification of these erosion-control structures.

The term "permanent type dam" refers to the function of the dam, as well as to the materials from which it is constructed. In using the term, Service technicians mean that the dam is so located that permanent mechanical control of the excess water passing down a slope is required. In other words, the concentration of water in the particular location will produce a velocity which might preclude the use of vegetation as a successful control measure. Permanent type dams are used for channel stabilization only

where vegetation would be insufficient to control erosion caused by running water and should function over as long a period of time as practical. Construction materials should be as durable as possible. Permanent type dams are also used for impounding water for consumptive use and for spreading water in flood irrigation systems.

In addition to these 289,320 permanent dams, the Soil Conservation Service has installed more than a million temporary structures to supplement vegetation in controlling gullies. These temporary dams are temporary in function as well as in construction, and seldom exceed 18 inches in height. They must necessarily be inexpensive; only available native materials such as logs, poles, planks, brush, straw, and loose rock are used in their construction. Most of these temporary structures have been installed in expanding gullies, and in many instances nondurable materials such as soft wood, poles, and brush have been purposely selected so that the structures will rot out after stabilizing vegetation has become established. This permits the formation of a smooth, bottom channel-way, and has been especially effective in preventing an excessive accumulation of silt that might cause shallow waterways to fill too rapidly, with resultant overflow and damage to adjacent lands.

Many of these temporary dams have been constructed in native depressions and meadow strips in order to provide temporary stabilization until vegetation is established sufficiently to check erosion. In some instances, early disintegration of the small structures makes it possible, in case of excessive silting, to plow a furrow down the center of the waterway and obviate the danger of overspilling.

Once vegetation is adequate to control erosion in the gullies, there is no further use for a temporary dam. As a matter of fact, its existence over a longer period of time would often be objectionable. In some locations, principally in the more arid regions of the country, or in places where the damage from concentrated water necessitates a longer period for the establishment of controlling vegetation, the dams may be designed to last from 4 to 6 years, or even longer.

FARM PONDS FOR WATER SUPPLY AND FLOOD CONTROL

By W. H. McPheters

Extension Agricultural Engineer, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.

By the Use of two spillways, it is possible to utilize farm ponds for both water supply and flood control. A pipe spillway could be put in at the low water level and a flood spillway at the high water level. This type of pond could be owned jointly by the farmer and the Government, the farmer owning the water below the pipe spillway and the Government the water capacity between the two spillways. The top few feet of the pond would normally be empty and would be available for the temporary storage of excess water. The size of the pipe spillway would determine the length of time the excess water would be held back from the stream.

For ponds of this type, it would not be necessary for the Government to buy the land or for the farmer to sign an easement for public access to the land. Both would contribute to construction costs in accordance with the benefits received.

HIGHWAY CONSTRUCTION AND WATER CONSERVATION

By R. D. Brown

Bureau of Public Roads, U. S. Department of Agriculture, Washington, D. C.

The Bureau of Public Roads is, of course, primarily concerned with highway construction and matters directly related to such work. Highway improvement in a broad way has intimate dependency upon land utilization and population distribution. Highway design and construction also have a more or less direct relationship to drainage and the Bureau has been engaged for many years in the broad field of soil physics and soil chemistry. The informa-

tion which we have developed to a stage of practical utilization in this field has an important bearing upon future highway design and construction policies.

The Bureau has entered into a cooperative agreement with the Soil Conservation Service to exert its influence in following any Federal, State, and local highway construction methods and practices for the purpose of developing improved methods and practices from the soil conservation standpoint. Because of the Bureau's interest in the whole subject as it relates to highway improvement, the Bureau stands ready to assist in any possible way in adapting design and construction of highways to the conservation of soil and control of ground and surface waters.

The matter of utilizing road embankments as dams for impounding and storing water in certain areas of the United States has been presented to the Bureau from a number of sources. This is particularly true in connection with the smaller streams in drought areas. The purpose of such plans would be to raise the level of the ground-water table by retarding run-off following seasons of precipitation. The incorporation of water conservation structures in the design for highway improvements would reverse the conception of highway construction that has existed through the years. The principal concern with respect to both rail and highway construction in the past has been to provide bridges or culverts of sufficient opening or water-carrying capacity to permit the passage of water at flood stage through such openings without damming it up and causing it to overflow private property. Since excessive moisture reduces the bearing capacity of soils and is a determining factor in producing damage to highways because of frost action, we have been concerned with preventing moisture in excessive quantities from reaching the subgrade of improved highways.

The idea of combining road construction with water conservation would mean that in the place of bridge or culvert openings to permit the free passage of flood waters, the highways would be carried on embankments which would serve to impound such water. There is nothing particularly difficult from an engineering point of view in doing this although in most instances it would be more costly than highway construction with openings for the passage of water. Any embankment placed to impound water would necessarily have to be constructed by special methods to secure stability and minimize the possibility of seepage of the impounded water through the embankment. In some cases this might mean the construction of a concrete core wall. In all cases the embankment would have to be provided with a spillway or relief gates which would allow the impounded water to be discharged at flood periods.

Aside from these considerations would be the question of private property rights. Before construction of this character could be undertaken it undoubtedly would be necessary for the State or some local agency of government to purchase or secure easements on the property which would be flooded by the impounded water. The extra cost of special construction not directly related to highway work and the acquisition of flood rights could hardly be considered a proper charge against Federal highway funds administered by the Bureau under existing legislation.

There have been one or two instances in which I believe the Bureau has participated in the construction of relatively short embankments in lieu of bridges for the purpose of impounding water. In these cases flood rights were granted by the property owners or were obtained by the State or other agencies so that there were no complications present such as undoubtedly would arise in connection with an extensive program of this character.

The Bureau's attitude toward more effective land utilization is entirely sympathetic and we stand ready to cooperate in the fulfillment of any sound proposals adopted for accomplishing this objective.

MALARIA CONTROL

By L. L. Williams, Jr.
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Whenever water is impounded for storage, soil conservation, or other purposes in the southeastern United States, it is necessary to take measures to prevent the production of the malaria-carrying mosquito in these ponds. Provision for control of this mosquito (*Anopheles*) should be an integral part of the plans of the project and maintenance of such control should be assured. Of the nine species of this mosquito in the United States only one transmits the disease east of the Rocky Mountains, namely *Anopheles quadrimaculatus*. Prevention of the production of *quadrimaculatus* means prevention of malaria in most of our country.

Anopheles quadrimaculatus breeds in quiet waters. It requires some sunlight, but it also requires some shade. Its favorite habitat is a pond with trees on or near the bank with water vegetation in the shallower portions amongst which is a good deal of drift flotage. This gives an abundant food supply, harborage against natural enemies, such as minnows and predacious water insects, and also protects these delicate larvae from the highly destructive action of waves, the smallest of which soon drowns them. Newly impounded waters without previous basin clearance offer the most ideal breeding places for anophelines. Land vegetation is killed and supplies a rich flotage, partly submerged trees, bushes, and grasses at the pond edge offer perfect harborage and shade and there are no natural enemies. In a few weeks, *quadrimaculatus* production becomes excessive. It remains abundant until all emergent land growth has disintegrated, flotage has been stranded or sunk, and a biological equilibrium has been established. This process usually requires a period of years of which the first 3 are the worst.

When the adult mosquito emerges from its water stage (1 to 2 weeks), it can acquire malaria if it feeds on an infected individual. After incubation for 12 days, it is capable of infecting anyone it may bite. Thus *A. quadrimaculatus* may spread malaria to the limit of its flight range, which is 1 mile from its breeding place.

Improper impoundage of water will always cause malaria epidemics in our southeastern States. It may bring a return of malaria to sections long since free of the disease.

During the Civil War days, malaria was prevalent in very nearly all of the inhabited portions of the United States. It extended from Florida and Texas into southern Canada, and was marked along the northern borders of the Great Lakes. The malaria line receded southward during the next 50 years, and by 1912 its northern border was approximately the Mason-Dixon line. The upper Mississippi Valley and the valleys of its tributaries, particularly in Indiana and Ohio, have been the scene of some of our worst and most explosive malaria epidemics; now this basin is a very healthy section. This recession of malaria took place prior to the commencement of antimalaria work in our country, which did not commence until the year 1912. It is significant that this rapid and marked recession of the disease took place in that part of the country where the greatest amount of major drainage had been carried out, which eliminated breeding places of the *Anopheles* mosquito. It may be readily seen that in any soil conservation program which requires the construction of innumerable small ponds, the engineers must be wary of bringing back the malaria conditions of 50 years ago. The 16 southeastern States from New Mexico to Virginia have for years prosecuted malaria control. Water may not, and should not, be impounded in this area without adequate provision for controlling production of *A. quadrimaculatus*.

Anopheline control is secured on large hydroelectric and navigation lakes through water level fluctuation, shore clearing and larvicide distribution. The basin is completely cleared of all vegetation which would be emergent at the

lowest water level to prevent flotage. The shore line is cleared back from the high-water level to prevent shade. The lake level is lowered at the commencement of summer to strand the winter's flotage collections and leave as much clean shore as possible, so that wave action, natural enemies, and sunlight may destroy *Anopheles* larvae. From time to time the water level is slowly raised to carry new flotage up to the high-water contour and then suddenly lowered 2 or 3 feet, thus stranding debris and recleaning the shore line. In addition, larvicides are distributed at weekly intervals over the shallow flats of the upper reaches and bays indenting the shore. This often requires the spread of thousands of gallons of oil by spray pump or motor pump from launches, and dusting with tons of paris green from hand-operated dusters, power blowers, or even by airplane. Expensive as these measures may be, they are economic, for the cost of malaria is even greater, the annual loss to the South being estimated at approximately half a billion dollars.

The principles of anopheline control for large lakes apply equally to ponds of smaller size, excepting only the expense of organization. Local power supplies, swimming and other recreational lakes can be prepared in the same manner as large ones. However, ponds of 50 to 150 acres can be cared for by one laborer. In such ponds it is usually sufficient to hold the water level during the winter 2 to 3 feet above that required during the summer, and lower it but once to strand the flotage which collected during the winter. Baffle boards in the spillway can accomplish this. Larvicides spread each week by the lone laborer can be depended upon to prevent *Anopheles* production for the rest of the season.

The construction of innumerable small ponds such as is contemplated in the program to control soil erosion seems to present a different problem. It would be easy to provide the physical means for water level fluctuation, but who would attend to it? It is manifestly impossible to maintain an organization to fluctuate the level of each of 2 or 3 hundred thousand ponds. These ponds are only constructed where erosion is so great that they will fill with silt in from 1 to 3 years. Under these circumstances there is need only for temporary mosquito control at each impounding. Those persons locally interested who having seen the necessity for erosion control have secured its commencement, must accept the responsibility for malaria control and must assure its maintenance. Through local means they must either provide for manual cleaning of the pond or the distribution of an inexpensive larvicide, or both. Directions for and supervision of these inexpensive measures of temporary malaria mosquito control should be a part of any soil conservation program.

SPREADING WATER OVER ABSORPTIVE AREAS FOR STORAGE UNDERGROUND

By A. T. Mitchelson

Senior Irrigation Engineer, Bureau of Agricultural Engineering, U. S. Department of Agriculture, Washington, D. C.

The Study of underground water conditions has been in progress throughout the Nation for some time, but the extent and quality of these supplies have been under particular scrutiny during the past several years of meager precipitation. The greater part of our country now witnessing a descending water table must await the return of normal precipitation and consequent watershed run-off before there will be restoration of normal ground-water levels. In other words, only through natural processes can this recovery be effected.

In our western country, particularly in the sections where irrigation agriculture is practiced, scanty precipitation of recent years has not been the only explanation of the lowering of our underground levels, for the scarcity of surface water supplies, either flowing or stored, has greatly accelerated the installation of pumping plants with underground basins as their source of supply. These two factors—decreased pre-

cipitation and increased draft—obviously present a serious threat to the sufficiency of supply for any period of time in the future. It naturally follows that in years of low precipitation there is need for more artificial irrigation which, as has been stated, increases the draft on stored supplies, and, in this case, underground storage.

Fortunately, in certain areas of our far western States we do not have to rely entirely on the natural percolation of precipitation from the surface to the underground basins.

In one section of southern California, specifically known as the South Coastal Basin, the streams running into this basin have small and steep watersheds not permitting of economical surface storage, but in the lower levels of the South Coastal Basin there are 37 distinct groundwater basins covered by a surface area of about 840,000 acres. These subterranean reservoirs, filled with porous alluvial materials, catch and store much of the waters precipitated during the erratic storms of the rainy season for recovery to the surface during the dry season. If it were possible to construct surface storage reservoirs in order to store and regulate the storm run-off above them the value of these basins would be enormously increased because of the extension of the period of run-off; but as has been stated, this is not economically feasible. Obviously, therefore, this underground storage is dependent upon the duration and intensity of precipitation. The natural process of under-ground storage is seepage of precipitation falling on the valley floor, flood waters flowing naturally over the alluvium, and return water from irrigation. However, natural means of contributing to the underground supply have not been adequate in this specific case, because the area embraced involves probably a greater increase in population and growth in agricultural and industrial development than any other area in our entire Nation in the same period of time.

About 90 percent of the water supply originating in the South Coastal Basin comes from ground-water basins, and while it has been stated that the actual area covering the 37 basins approximates 840,000 acres, the entire acreage of the area served by water drawn from them is approximately 2,500,000 acres, of which about 70 percent is irrigated agriculture or areas using domestic and industrial water. Consequently, this increasing demand on the underground supply with insufficient recharge has resulted in a rather serious overdraft and constantly lowering water table. In order, therefore, to augment the natural process of replenishment of these basins, we resort to an artificial process devised to stimulate percolation and which we refer to as water spreading. This simply means that we divert the flood waters from their normal channels onto the spreading grounds and by adopting one or a combination of several spreading methods, we greatly increase the area exposed to percolation. Incidentally, we also control the flow and prevent flood damage to lowerlying areas.

These spreading grounds are usually near the mouths of canyons where the streams begin their meandering course over the flatter lands in their passage to the sea. The formation of cones as the streams progressively drop boulders, gravel, sand, and silt, consequent upon reducing velocity, makes possible the location of these spreading grounds. The surface areas of these cones vary from a few acres to over 5,000 acres, depending on the size of the stream.

There are, of course, various ways of diverting the water to these spreading areas, but care must always be taken to provide perfect control of both the diversion of water from the stream and the return of water left after the total spreading area has been wetted.

There are four general methods of spreading water for storage, namely: (1) The basin method, (2) the ditch method, (3) flooding of land in state of native vegetation, and (4) by recharging the underground storage directly by means of wells, shafts, or tunnels.

The method to be adopted in any given case must be determined by a study of all the prevail-

ing conditions, since each of these methods has its merits; or it may be, as in several cases of our California spreading systems, that a combination of two or more methods can be used.

For a number of years water spreading has been practiced in southern California, but the systems were small and detached, lacking adequate financial support and modern technical direction. The pioneers deserve all honor for their efforts, but the systems were not efficient.

During the past 4 years, support from State and Federal agencies, mostly as a relief program, has resulted in an enormous amount of conservation work so that now every stream in the southern area has some sort of modern and efficient spreading system.

The city of Los Angeles has developed a very efficient spreading system which it operates partly as storage for seasonal surplus water from the Owens Valley development and partly as conservation of storm water from the San Fernando Valley watershed.

Perhaps as a more typical case of what has been done in combining upstream control and underground storage in the valleys is that of the Santa Clara Valley Water Conservation District in Santa Clara County, Calif. This conservation district—a political subdivision of Santa Clara County—covers an area of about 130,000 acres comprising approximately the level floor of the main portion of Santa Clara Valley.

The city of San Jose, with a population of about 75,000, is within the district, as are several other smaller towns, altogether comprising a population of about 110,000. The assessed valuation of the land alone in the district is close to $40,000,000, and the total assessed valuation of land and improvements is about $85,000,000. Nearly all the district area, or approximately 85 to 90 percent, is under intensive cultivation. Three-fourths of it is deciduous fruits, the balance truck and gardening. Nearly all the district is irrigated by water from wells, and much of the domestic and industrial supply for the urban areas is similarly obtained. Recent records show the operation of about 2,000 pumping plants.

Up to some 22 years ago a large portion of the area, including the town of San Jose, had artesian water; but about 1915 subnormal precipitation resulted in a constant lowering of the water table. Pumping lifts increased 100 feet or more, and annual power costs for pumping grew to $665,000. Unlike the situation in the South Coastal Basin, this central California area has no large detrital cones. There are alluvial beds, but their formation has been brought about in a different way. Also, unlike the South Coastal Basin area, the Santa Clara Valley is fed by streams having several excellent surface storage sites in their upper reaches.

The remedial measures necessary to arrest recession and restore the water table to normal levels were, therefore, modified to fit these different geological and topographical conditions.

Five principal surface storage reservoirs were constructed on the main streams with a smaller one on a minor stream. These are intended as detention reservoirs, although one of them now having a capacity of 30,000 acre-feet can be enlarged to accommodate an increase of about 50 percent. Water is stored in these reservoirs during the rainy season and released under perfect control to flow over the alluvial materials below at a rate gaged by the ability of the soils to absorb and percolate it to the underground storage.

The rainfall records of this area show another favorable feature for this system—that is, the storms are usually so spaced in time as to permit of several fillings per year and, of course, a longer percolation period. The 2 years of operation (1 year when the project was only partly complete) show most encouraging results.

Briefly citing last season's operation of the system, an example of the effectiveness of the works may be seen. The last season's run-off was so concentrated that most of it occurred in a period of about 2 weeks and most of it would

have been wasted had the storage reservoirs not been in a position to intercept it. Official gaging stations show that during the February storms the total run-off into the district was about 87,900 acre-feet, as compared to a run-off of about 100,000 acre-feet for the entire previous season, and for this season's total run-off, up to February 29, of about 98,000 acre-feet. By the end of February (1936) the district reservoirs had intercepted and were then holding in storage about 33,000 acre-feet, and there had passed into the district from reservoir releases and uncontrolled streams 53,870 acre-feet, of which about 27,500 acre-feet, or 51 percent, had been passed into underground storage. From records it can be shown that during the prolonged flood stages of February 1936, when most of the season's run-off was concentrated, the waste in the entire valley amounted to only 31 percent of the seasonal run-off, whereas it would have amounted to 68 percent had there been no upstream storage.

It is anticipated that as soon as sufficient run-off is available, releases from the reservoirs can prolong the run-off season so that throughout the irrigation season water can be held on the percolation works above the surface of the gravel cones of the main streams.

For the past 6 years the Bureau of Agricultural Engineering has been making studies of the various important factors influencing percolation of water and the several methods of spreading. These investigations are being made on experimental plots under complete control and on areas where spreading is being conducted on a large scale and under comparable methods. They include investigations relative to rates of percolation in different soil types, the relative merits of the different methods of spreading, the difference in percolation factors of areas denuded of vegetation and treated according to the several methods usually employed in those areas still bearing their native growths undisturbed, the effects of a fluctuating water table on the rate of percolation, the effects of temperature, and many other influencing factors.

ARTIFICIAL METHODS OF GROUND-WATER RECHARGE

By Ross Nebolsine

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Mr. Bennett and other speakers have definitely demonstrated the paramount importance and influence of the conditions of the surface of the ground (principally the character of the vegetative cover), on the rate of soil erosion. However, some doubt is raised as to whether the improvement of surface conditions can achieve water conservation to a similar degree. In some cases floods may be increased by the presence of forests which retard the melting of the snow until the period of warm spring rains and, in certain regions, the increase of vegetative cover may reduce the total quantity of water available because of evaporation and transpiration losses.

Vegetation may be the first of several obstacles in the path of rain water to deeper ground storage. The condition of the surface of the ground may be ideal for infiltration but if there is a horizontal impervious clay stratum 10 to 20 or 50 feet down, the recharge of the ground storage may be difficult. Even discontinuous lenses of clay and fine sand may offer considerable resistance to vertical percolation. Alluvial material even though it consist of porous sands and gravels can at times offer great resistance to vertical infiltration because of the horizontal stratification in alternating finer and coarser layers. Moreover, the sand particles settling down through the water on their flat sides often assume a position that creates increased resistance to vertical infiltration. An easy demonstration of this can be had by comparing coefficients of vertical permeability of similar mixtures of sand and gravel, one deposited in the dry state and the other settled through water.

The Great Plains area is described as consisting largely of alluvial materials. There may be locations in this region where it will be possible to increase artificially the amount of water that

enters the deeper ground storage. Certain studies, experiments, and work done by Mr. Ranney and myself indicate this possibility by new methods and apparatus.

This process permits artificial recharging of the ground water under conditions where ordinary water spreading would not be effective. This is made possible by capturing part of the excess flow from streams with sandy beds and feeding it through shafts to the available underground porous formations.

We have already found several regions where there is little or no vertical infiltration to maintain the underground supply and the water table has been falling. For instance, in the region of London, England, blue clay overlies the porous water-bearing sand and chalk basin and retards vertical infiltration. A similar condition will prevail in the Tagus Valley near Lisbon, Portugal, when the porous water-bearing strata below the alluvial fill is heavily drawn upon. There may be similar situations in the Great Plains region.

Under certain conditions, it is possible to augment considerably the ground storage by water spreading and by the process of artificial ground-water recharge. This will permit in a number of cases the recovery of water already in a stream and add it to the underground storage where it is most effective and useful for water conservation purposes.

GROUND WATER FOR DROUGHT RELIEF

By Joseph Jacobs
Consulting Civil Engineer, Seattle, Wash.

Ground Water as a means of drought relief merits far more consideration than it has yet received. If a particular area is already charged with a dependable body of ground water from local or upstream sources, or which, by upstream storage or other upstream operations, can be so charged, the basic conditions are favorable for relief by ground-water utilization. All of the drought-stricken sections of the plains country should be intensively investigated as to the extent and availability of ground-water supplies, the fluctuation of water tables, and the possibilities and methods of recharging from upstream sources. With cheap power for pumpage, ground-water supplies may prove the most hopeful source for the relief of drought-stricken areas. It is believed that it has as great, or greater, economic promise than has shallow pond storage with the unavoidably heavy evaporation losses which attend that process.

ZONING AS A TECHNIQUE FOR WATER CONSERVATION

By George H. Gray
Land Planning Consultant

Zoning is a means of exercising many of the controls necessary for the conservation of our soil and water resources. There is abundant precedent for comprehensive zoning of this type. In fact many existing State regulations for the use of water are in essence zoning regulations and are in themselves enough to establish the validity of an application of the principle. Additional precedent can be found in municipal zoning, in county zoning, and in State zoning for various other specific purposes; and, antedating these by many decades, the building set-back requirements, tenement-house regulations, fire regulations, theater regulations, and general building laws. All of these impose limitations on private property in the interest of public health, well-being, and safety. They involve no compensation, since in principle the restrictions apply to all alike and all alike share in the benefits.

In effect, the zoning for the control of water would mean the coordination of existing regulations and rounding them out with such additional regulations as might be needed to form a comprehensive policy for the conservation of the waters of the State. With the several States so zoned, regional control of the waters would become possible, and entire watersheds could be brought under a coordinated and comprehensive control. No less than that is necessary to a thorough-going policy of water conservation.

CHAPTER IX

Conservation of Wildlife

UPSTREAM ENGINEERING AND THE CONSERVATION OF WILDLIFE RESOURCES

By the Bureau of Biological Survey, United States Department of Agriculture

The Bureau of Biological Survey appraises the Upstream Engineering Conference a great forward step in conservation. We say this because we realize that the nonliving and the living elements of our natural resources are so closely interrelated that they must be considered together in the conservation and utilization of any one of the natural resources of the Nation. The use of one resource or class of resources without due consideration for the welfare of the others is likely to result in a loss from a national standpoint.

THE BIOLOGICAL SURVEY NEEDS ALLIES IN WILDLIFE CONSERVATION

The work of the Bureau of Biological Survey in its efforts to preserve and perpetuate the wildlife resources of the Nation is already well known. It has been a long and uphill fight in the face of opposition deep rooted in unwise and heedless soil mining, deforestation, drainage, and irrigation practices. The exploiters and the wildlife conservationists have been strenuous competitors, and in championing the cause of the latter the Biological Survey welcomes aid from every source. The technique and methods of our newly developed and applied sciences of soil conservation, upstream engineering, and reforestation fortunately include many measures that should serve to protect and augment the Nation's wildlife supply.

Therefore, in the present technical consideration of upstream engineering practices, the Biological Survey invites serious consideration of the application and even the modification of such methods and practices in order both to safeguard and to increase our wildlife resources. The Survey is confident from its own work in wildlife conservation that these objectives can be attained and urges that sight not be lost of this great opportunity for all-around conservation of our natural resources.

By adopting a wildlife program, some of the Federal agencies—including the War Department, and in the Department of Agriculture, the Forest Service, and the Soil Conservation Service—will be able to supplement the wildlife work of the Bureau of Biological Survey to an important extent. Simply by becoming wildlife conscious and weighing wildlife values in relation to other aspects of the undertaking as well as the benefits to society that will accrue from wildlife conservation, the engineering forces probably can change the current from a fast diminishing to an increasing flow of wildlife resources of local communities.

HOW UPSTREAM ENGINEERING CAN BENEFIT WILDLIFE

Someone has said that rivers are born in hills. Both literally and figuratively speaking the wildlife of the Nation is in the hills today. By this expression we refer not only to those game pockets which by virtue of their isolation have managed to maintain themselves in varying degrees of primitiveness, but also to the plains

and plateaus where, because of intense cultivation or industrialization, wildlife habitat is now at a minimum.

Such wildlife as exists in the lower reaches, is beset on the land by the evils of clean-culture farming, alternate devastating floods and recurrent droughts, deforestation, and soil erosion; and in the water, by siltation and the pollution resulting from industrial waste and sewage. If in their efforts to remedy these afflictions, upstream engineers will keep in mind a few basic concepts of modern game management, the cause of wildlife conservation in this country will be greatly benefited. In reality the requirements of any particular species of upland game or other form of wildlife are relatively simple, consisting of a handful of essential foods, an assured water supply, and safe refuge or cover.

We believe that upstream engineering, as now conceived, very definitely admits of catering to the needs of indigenous wildlife creatures without much added expense. For example, soil-conservation workers in arresting certain types of erosion can achieve the desired end in many instances by using plants, trees, and shrubs that are of known food or cover value to wildlife. The forester also will gain his own objective in retarding the run-off and at the same time greatly increase the range for wildlife if he will mix with his plantations of pure-stand commercial species, patches of food-bearing shrubs and moisture-holding perennial grasses. The restoration of this food-bearing understory in forested areas where it has been damaged or destroyed is one of the most important steps that can be taken in the management of forest lands for wild turkeys and deer in the eastern United States alone. On the engineering side it may be observed that impoundments by structures built for retarding run-off and for conserving the water supply will be of inestimable value to many forms of wildlife.

Work on headwater streams, if embracing the new practices of stream improvement which are so vital from the standpoint of both the angler and the fisheries' worker, will restore miles of streams that now have only periodic flow and will revive springs that have long been dormant. This can add hundreds of miles of living streams for angling and other recreational interests and many acres of impounded water for various recreational and wildlife conservation activities.

In illustration of upstream engineering in relation to wildlife, consider the miles of rivers and brooks that can be rehabilitated biologically by the simple process of mine sealing, if this is done thoroughly. Look at the miles of watercourse that can be restored to wildlife and recreational use if in specific instances upstream engineering dictates that a sewage-disposal plant should be installed where there is a concentration of human population. Again the stabilization of lake levels will restore thousands of acres of wildlife habitat, for upon the shallow parts of our lakes many of our most important wildlife species are dependent, the deeper parts being relatively unproductive.

As a further example, the reduction of the silt load of our streams and rivers will make hundreds of miles of formerly productive fishing waters again available. The movement of silt and sand in many of our most important river systems has long since driven out the most important game food fishes. The arrowy rush of a salmon or trout and the vigorous surface strike of a bass are no longer known in many a mile of streams in which formerly these fishes naturally abounded.

The Biological Survey would like to point out at this time that the availability of wildlife habitat will be greatly increased by the upstream engineering program. This applies with particular emphasis to the Appalachian highlands and the Piedmont plateau. This great area, embracing as it does the mountainous and hilly uplands of 12 great States, is for the most part entirely barren of migratory waterfowl or other bird refuges of types that can be established by the Bureau. Because of the fact that refuge undertakings here are greatly complicated and beset by the very factors of water conservation and upstream planning with which you are

confronted in this meeting, the Biological Survey has not been able to institute adequate operations for wildlife conservation in this great district. Parts of at least two great migratory bird flyways traverse this region and it is important that ultimately we have definite resting and feeding places there for the migratory species. Resting and feeding refuges are essential along waterfowl flyways and should be located with due regard to the lines of flight, points of concentration, and places of overshooting. Any flood control or storage project that may later be established in this area will be a great factor in satisfying this need. It is interesting to note that the few reservoirs that have already been built in this region are utilized by migratory waterfowl and other valuable species.

UPSTREAM STORAGE VERSUS DOWNSTREAM FLOOD CONTROL

It is heartening to see the efforts that are being made by various agencies in the control of floods and of the devastation of productive soils through arresting erosion. These endeavors have come at just the proper moment, both psychologically and from the practical standpoint to prevent complete destruction of some of the most damaged areas.

The Biological Survey wishes to go on record as being in favor of the type of headwater watershed control contemplated by the best upstream engineering philosophy. Better headwater control and water retaining power mean fewer expensive and short-lived flood reservoirs downstream. It should be recognized that the longevity of the biggest storage dams is often directly proportional to the extent that erosion control and water retention are developed by the proper treatment of a particular watershed. We have only to look at the alarming rate with which some of the largest power and reclamation reservoirs are silting up to recognize the significance of this statement. The retention in usable condition of reservoirs both great and small is highly desirable for wildlife preservation.

UPSTREAM ENGINEERING METHODS VERSUS WILDLIFE

Let us repeat that wildlife will benefit in the upstream engineering program in direct proportion to the engineer's consciousness of its needs. In many instances by a slight alteration of his plans and methods he not only can accomplish his own work, but he can help to perpetuate valuable wildlife resources. To further elaborate on this point, let us refer to the manner in which most flood control or storage projects are operated.

Usually, storage reservoirs are designed to impound large quantities of water that will be discharged with proportionate rapidity. They simply serve as an elastic diaphragm to regulate the pulse of water flow in that basin. At flood-level discharge, the water is too deep to foster wildlife; and after the complete discharge of the flood storage, the reservoirs are reduced to mere mud flats, with attendant destruction of fish, life, waterfowl food, and many other features beneficial to the wildlife concentrated there. How much more sensible it would be to establish a minimum spillway level below which the water could not be drained, thus protecting biological interests, promoting diversified use, and hence the value, of the project, and, at the same time, taking less than 5 percent of its flood-storage capacity. Low dams should also be constructed across shallow arms of reservoirs to maintain the stable water levels that are essential for the production of aquatic foods of wildlife. By such retention of what might be called "conservation pools" adjoining flood reservoirs, these projects, rather than being a detriment, could in many cases be made an asset to wildlife.

THE WATER RIGHTS OF WILDLIFE

In almost every water-basin study that has been made in recent years, if any mention of wildlife can be found at all, it will be submerged in a single inconspicuous paragraph referring vaguely to a proposed future study bearing on

the welfare of the wildlife of the basin. Unfortunately for wildlife, such a follow-up is rarely if ever made. Since water is universally vital to wildlife, the time has come when all who are concerned with the conservation of the Nation's resources must definitely and steadfastly support the concept that allocation of a reasonable quantity of the water in any drainage basin for wildlife is an entirely legitimate use. This concept has ample social and economic foundation in the fact that the modern American standard of living and the public welfare demand adequate recreational facilities, and that of the Nation's recreational opportunities, wildlife forms a great and indispensable part. As an illustration, we have only to consider the enormous annual turn over in industries that cater to recreational pursuits, and to reflect that enjoyment of the creatures of the outdoors provides a great part of the attraction and opportunities for such recreation.

It is not enough that modern man shall be economically productive. The imperative demand of law-abiding citizenship and of wholesome living is that there be adequate recreational opportunities. The maintenance of the Nation's wildlife resources is inextricably interwoven with the whole of the Nation's recreational activities. Failure to recognize the part wildlife plays in recreation and to take adequate precaution for its maintenance on a permanent basis is ultimately to court social and economic disaster. It does not seem, therefore, that wildlife can be ignored in any comprehensive, well-considered plan for the utilization of land and water resources.

There can be no question of the importance of utilizing water resources for the benefit of wildlife, even in the vast irrigated areas of the West, where in the hurry to put every available acre under irrigation, wildlife has been driven to dry lake bottoms and to mountain tops, in neither of which places can it permanently exist. However, the tide is turning and we now see an increased public recognition of the need for the recreational enjoyment that adequate wildlife resources only can provide. In some regions enlightenment (or more often mere chance) has resulted in the saving of residual wildlife on areas where under careful fostering and modern game management practices it can be restored to something of its former abundance. We do not mean to say that wildlife interests should prevail over human interests, but that both can enter the program. For example, in the Rio Grande Valley thousands of acres can be irrigated and still leave, unchanged, here and there, a few thousand acres to perpetuate the indigenous wildlife. Under the excuse of further development of agricultural lands these small residual areas should not be taken over for cultivation. This illustration is a real one and similar situations are facing the Biological Survey on countless areas today. At the present time, practically the only watered wildlife area in that valley not yet drained or used for reservoirs is a small tract the Biological Survey is desperately trying to maintain for wildlife in the Bosque del Apache area in New Mexico. There is, however, an almost overwhelming demand for the remaining few acre-feet of water necessary to keep wildlife alive in this area.

To summarize, the Bilogical Survey has attempted here to indicate its general reaction to upstream engineering planning and operations and to demonstrate that a broad interpretation of this work would be a great boon and advantage to wildlife. Moreover, the Bureau does not stand detached from this great engineering work and study but by virtue of the mass of data on wildlife, accumulated throughout its history, bearing on the ranges and habits, and on the food and cover requirements of all the Nation's important game and other wildlife species, the Biological Survey is in position to give practical advice and guidance in wildlife management and to make its diverse force of field biologists and game-management agents available for consultation and practical demonstration along the lines here stressed.

RELATIONSHIPS OF ANIMAL LIFE TO LAND AND WATER RESOURCES

By Clarence L. Forsling
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After more than half a century of inattention to repeated warnings, the Nation has at last awakened to the fact that the manner in which we treat the land where rain falls has a vital bearing on water control and soil erosion. So today we find engineers, foresters, biologists, and agriculturists joined in a national upstream engineering conference to coordinate their ideas on how to deal with this major problem. This meeting follows another equally memorable and much more far-reaching event; namely, the passage by Congress in 1936 of a flood-control act, which, in addition to structural engineering, for the first time in our national history recognized that the correction of conditions on drainage surfaces is an important integral part of a comprehensive flood-control program.

Gradually we have come to recognize that we must not think of surface water as contributing only to navigation of the larger streams or as a source of power for industry—and as such to be controlled only by large dams and reservoirs. Gradually this country has come to see that its surface water must be thought of first of all in terms of its ability to support life—both plant and animal—in the degree that is needful to human welfare on the land. At the same time we have come to realize more fully than ever before that plant and animal life can be made to play a very important role in maintaining the highest usability of water for all purposes. This biological phase of upstream engineering is nothing new. What is new is that thinking people have become aware of the fact that we cannot upset natural balances without serious consequences unless suitable substitutes are provided for them.

Animal life on watershed areas, in relation to control of surface waters, may be considered in two aspects. One is the dependence of animals, large and small, on the proper distribution of surface waters; the other is the influence that the preservation and well-being of this animal life may have on water conservation and control. Although practically every form of wild animal life bears some relationship to the plant-soil-water complex, of particular interest in this relationship are burrowing rodents, waterfowl, fish, and beaver.

The general tendency in our agricultural economy has been to regard burrowing rodents chiefly as a detrimental agent in land use. However, the fact is that these animals play an important role in creating and maintaining favorable soil-water relationships, especially on noncultivated land. The working of soil by many species of rodents, in a manner which can be accomplished in no other way, helps to maintain that openness of structure which is favorable to the intake of water. The vegetation carried into their burrows by millions of rodents, often to a great depth, and the carcasses left when the animals die, add to the organic content of the soil, which, in turn, increases the absorptive capacity as well as the fertility of the soil for plant growth. The exact contribution of rodents to soil-water relationships has never been determined quantitatively, but qualitative analysis and observation leave no doubt that it is large.

Obviously, excessive populations of rodents, to the degree that they cause material damage to crops, cannot be tolerated. What happens when the natural biological complex is severely disturbed is demonstrated by investigations in Idaho. A study of 371,000 acres within the Boise River watershed to determine the causes of accelerated erosion showed excessive population of pocket gophers to be an important contributing factor. The damage consisted of excessive loosening of the soil and the destruction of a part of the plant cover, both of which increased susceptibility of the soil to erosion. The excessive population of rodents, however, had come about, in part, through the reduction of their natural predators, more especially hawks

and owls, without the application of measures to offset the loss of this natural control. Furthermore, excessive grazing by livestock so reduced the feed supply that the increased population of rodents was forced further to overgraze the vegetation in order to subsist. However, the too heavy curtailment of these natural cultivators of the soil is also bound to be disastrous in the long run. The solution of the problem appears to lie in the hands of the biologist to devise suitable systems of control or management.

Although wild waterfowl do not contribute directly to water control, they are materially involved in the general water economy. In our eagerness to increase the farm area or reduce mosquito-breeding places, unwise drainage of many shallow lakes and sloughs—former temporary flood-storage pools and contributors to underground water storage—has not only accelerated surface run-off and erosion and reduced ground-water storage but has also greatly reduced the numbers of waterfowl. It has become recognized that, as in the case of many other natural resources, the supply of waterfowl is not inexhaustible, and that there is a close relationship between land drainage and decreasing waterfowl. Because it will serve the dual purpose of helping to restore the rapidly vanishing supply of birds and contribute directly to water control, the preservation of present waterfowl areas, restoring areas formerly so used and establishing new ones, is an extremely important part of any national upstream engineering program.

Fish, like waterfowl, may not contribute directly to water control. However, the conditions which are necessary in streams and lakes to supply this highly important economic and recreational asset are of real significance. Streams or small lakes which are frequently swept by floods or are being filled with silt do not afford a suitable habitat for most species of sport fish. These conditions destroy the food supply, spawning beds, and hiding places. Consequently the reestablishment and maintenance of fish resources further emphasize the need for the control of water and the prevention of accelerated erosion by whatever means. Furthermore, the methods of stream improvement for fish culture, including the establishment of checks in swift streams to create more pools, will aid in no small degree in reducing the velocity of streams and in increasing the subsurface water supply. Similar results will be accomplished by the creation of new small lakes or ponds primarily for the raising of fish. Thus the conservation of fish and the control of surface water are mutually beneficial.

Most important among all animal conservers of water is the beaver—the first and greatest "upstream engineer" of all time. Now reduced to a bare remnant of the former population, this animal once had its dams, such as college-trained engineers are undertaking to build today, in almost every small-sized stream in the United States. By building and maintaining their low dams along streams they created hundreds of thousands of small reservoirs which served to break the force and reduce the crest of floods, to desilt the streams and prevent channel erosion, to increase the ground-water supply, to increase stream flow in dry weather, and in many ways to improve the fish resources of streams and lakes. Although these dams may not have been regulated so as to serve as useful a purpose as those which the human species of upstream engineer will build, they made up in numbers what they lacked in systematic control. Furthermore, they were built at no cost to the landowner or taxpayer, and, finally, the beaver threw in his hide for good measure.

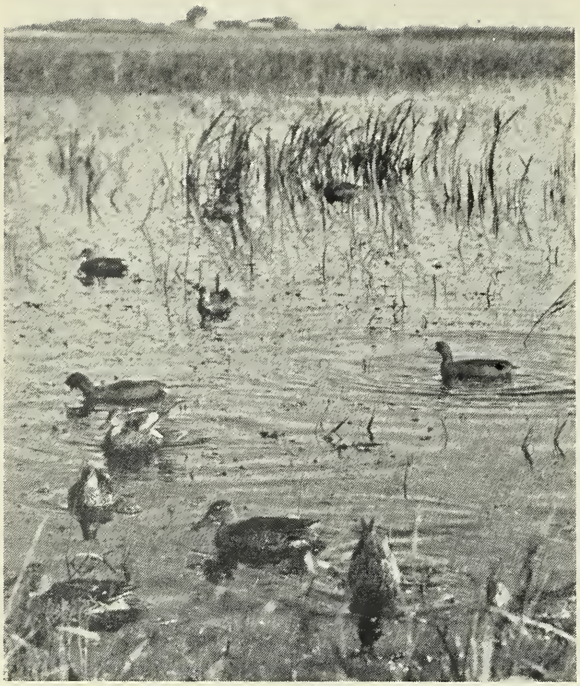
Information compiled by the Bureau of Biological Survey indicates that the beaver formerly was found in the smaller streams, lakes, and swamps practically throughout the United States except along the lower coastal plains area from Chesapeake Bay to the southern tip of Texas. For about 150 years, ending about 1850, in the central Rocky Mountains, beaver trapping and fur trading was the chief industry and business. But the value of the furs proved the

U. S. Biological Survey photo.

FIGURE 66.—A refuge for migratory waterfowl.

Photo by Allen Gold Co., courtesy U. S. Forest Service.

FIGURE 67.—The original upstream engineer at work.



U. S. Biological Survey photo.

Figure 68.

Photo by F. Rush; courtesy U. S. Forest Service.

Figure 69.

U. S. Forest Service photo.

Figure 70.

U. S. Forest Service Photo.

Figure 71.

HEADWATERS CONTROL AFFORDS A HABITAT FOR WILDLIFE.

downfall of the animal. It is now found in perhaps not to exceed one-tenth its former range, and where still in existence or reintroduced, the population, except in a relatively few localities, is far less dense than formerly. There is little doubt that increasing irregularity of stream flow and greater channel cutting were initiated in many parts of the North American continent when the beaver population was removed.

Like many other things, however, the beaver if uncontrolled is not an unmixed blessing. A great part of the original range of the beaver is now under cultivation and fields and orchards replace the primeval forest. Obviously it would be unwise to permit wholesale reintroduction because of the damage which would follow. But there are extensive areas where it could be reintroduced to advantage under proper control, and this usually is not difficult. Without control, some damage would be done on these areas by flooding valuable land, by destruction of some timber, and in other ways. The claim has also been made that beaver cause some damage to fish life, especially in relatively low, flat country, which may or may not be offset by the benefits to this resource. Students of beaver point out, however, that proper management will overcome most of these difficulties and at the same time make available the many benefits in water control and, in addition, yield an income.

As I see it, the whole job of upstream engineering on wild land is a twofold undertaking. Proper wild-land management including forestry, range management, and restoration of wildlife conditions will serve greatly to ameliorate floods and drying up of streams in time of drought, to reduce erosion and silting, and to enhance the use of water for industrial and domestic purposes. But neither land management nor structural engineering can expect to do the job by itself. The two are essential parts of one undertaking. If structural engineering is properly correlated with skillful wild-land management, then and only then may be hope to approach a wise solution to water conservation.

WILDLIFE—A LAND CROP FAVORABLE TO CONSERVATION OF WATER AND SOIL

By the More Game Birds in America Foundation, New York City

Ilin, in his "Men and Mountains", gives us the amusing supposition of an engineer who, without consulting anyone, set out to build a dam across a river. At first it appeared that the only problem was to build a structure of the required dimensions. Various interests which would be affected by the damming of the waters soon appeared, however, and urged their claims upon him. The engineer had to relocate his dam and modify his plans several times to avoid flooding valuable agricultural land, to make it possible for migrating fish to ascend the stream, to maintain an open waterway for navigation, etc. The story is appropriate because it shows in a simple way the extent to which mutually interacting factors may determine the nature of a final structure, especially if the work involves contacts with such a variety of fields as we must deal with in upstream engineering.

Here we are concerned first with water—water as it falls on the land and penetrates the soil and water as it appears in lakes and streams after running off the land or seeping through the soil. The conservation and restoration of water resources is understood to be our most needful enterprise. Intimately linked with this is soil conservation and our many types of land utilization. It is clear that unwise practices in land usage have brought upon us the necessity for speedy action in upstream engineering and it is just as apparent that the remedy lies in wise and corrective policies for raising our crops whether they be agricultural, forest, or wildlife. These policies seek to express the ideal of using the land so as to obtain the greatest possible return from it which is consistent with the permanent well-being of the soil and of our national economy.

Soil cultivation is, in a sense, the most artificial and disturbing treatment that man has imposed

upon the land. The protective natural cover has been removed. The plowed and harrowed earth is bare and exposed to the elements for long periods. Most crops even when mature do not offer nearly as much protection to the soil as the natural vegetation of grass, brush, and trees. Our farms are therefore in greatest need of upstream engineering and here the Soil Conservation Service has carried its attack directly to the land. The conventional dam is being used for water storage but of greater significance is the conception of the soil itself as both dam and reservoir. By contour plowing, terracing, and strip cropping this is accomplished and a new—an upstream—engineering technique arises.

This technique will by no means be limited to the simpler manipulative measures of the above but will include the choice of crops for different soils. In the great areas which have been abandoned by agriculture and in those parts of individual farms which should not be cultivated, because it will not pay or because of fear of erosion, the proper crop must be determined, although its nature may appear unusual to those who think of land crops in terms of cultivation.

The particular need of such areas is for a natural vegetation and the appropriate land usage will be that which yields the highest returns consistent with such vegetation.

Grazing of domestic stock, forestry, wildlife management, and recreation are the logical uses of natural areas. Grazing will, in general, be limited to open grass and weed areas and is not compatible with any one of the three other uses on the same area at the same time. By contrast, however, forestry, wildlife, and recreation are not only consistent, simultaneous uses but are more or less inseparable.

Forestry is commonly recommended for uncultivated lands which are not in pasture. Forest cover insures soil conservation and retards water losses which are all too common on bare land. Wood is valuable. Forests may exert beneficial climatic effects. We now regard trees as a crop much as wheat or corn. From the financial viewpoint, however, it is unfortunate that forest crops mature so slowly. Periods of 60 years or more are required to produce saw timber. An investment for this period accumulates staggering interest charges unless some periodic income can be realized from the lands to reduce these charges while the wood crop matures.

In wildlife as a land crop we have such an income which can be realized annually. Those components of the wildlife population which may be a source of revenue are fur-bearing animals, game animals and birds, and fish. These may be said to have values under three heads. First, there are the fish and fur bearers which may be caught in the wild or propagated on farms but, in either case, a directly salable product is obtained. Second, there are the game animals, birds, and fish which derive their value from the sport which they furnish and not from a market value. Thirdly, and quite aside from hunting, there is a definite but intangible recreational interest which an area has when it contains wildlife, especially game birds and animals.

On a great many areas all three of these uses could be realized simultaneously and with entire compatibility. At the same time forestry could be practiced. Some adjustments in conventional forest practice would be necessary to favor the game and fur-bearers but the revenue therefrom should more than compensate for this.

Fur, fin, and feather have a definite economic status. Although game species depend upon hunting for their valuation, this reaches a high point. With some 13 million hunters and fishermen in the country, the money spent on the sport runs into seven figures. Moreover, there is a tendency toward the sale of shooting rights to sportsmen by landowners, shooting-preserve operators, hunting clubs, etc. The day is definitely past when we can consider game as something that nature provides bountifully and all we have to do is shoot at it. The time has arrived to put game in the class of a land crop, to encourage the landowner to raise it, and make

it profitable for him to do so. When this has been done there will be far more game, and wild land will yield a welcome income.

Since the upstream engineer is keenly interested in water areas, he will realize the possibilities of these waters for raising fur, fish, and wild ducks. Ponds and lakes which must be created and marshes and swamps which must be maintained need no further justification than that they are needed to keep up the ground-water levels. However, these water areas will arise more spontaneously if they are recognized as capable of producing wildlife crops of high value.

The interest of Federal and State governments and also of sportsmen in migratory waterfowl has resulted in the restoration and maintenance of several million acres of water areas. The United States Bureau of Biological Survey has within the last 2 years restored over 2 million acres of permanent water-fowl refuges, most of them in the drought-stricken Dakotas and adjoining States. Many individuals and sportsmen's organizations have undertaken to create new water areas out of a desire to benefit waterfowl.

While speaking of the relationship of wildlife to upstream engineering we must not forget those original water conservationists—the beavers. These little fur-bearers whose name has become a synonym for busy-ness had the situation pretty well under control at the headwaters of our streams before trapping pushed them almost to the point of extinction. Under proper control they will again perform the same function in our woodland streams, if introduced and encouraged. There are already instances, such as in Oregon, where the dam-building activities of the beaver are being used to improve stream-flow conditions.

The uplands are no less promising for game production than the water areas. In farming communities where upstream engineering is so greatly needed there is a mixture of cultivated crops, grass and weeds, brush, and woodland. In certain sections all components of the picture are not present but in most seriously eroded areas they are. This mixture of vegetative types is eagerly sought by birds and it is most beneficial to upland game birds which have proven susceptible of practical game management. In the South this means the quail, and elsewhere, the Mongolian or ring-necked pheasant. Both of these game species are eagerly sought by sportsmen. They can be easily propagated in confinement and when released will adapt themselves to field conditions. Moreover, they will multiply in the wild state when the proper natural food and cover are available.

In upland game birds the farmer has a potential crop for his wild land. The areas favored by these birds are those of natural vegetation which counteracts soil erosion and aids water conservation. If State game departments will make it possible for the farmer to raise upland game birds and sell the shooting rights on his farm, the income from lands which cannot be cultivated will be visibly increased.

There is a beautiful interdependence between wildlife values and the aims of upstream engineering. Those who are charged with the carrying out of water-soil conservation work have an opportunity to bring wildlife restoration far along in its proper function as a water-land crop. In turn, the wildlife values, the sportsman's interest, and the landowner's support can mean much to the upstream program which must depend upon private cooperation for widespread success.

INFLUENCE OF ANIMAL LIFE ON SOIL AND WATER CONSERVATION

By Ernest G. Holt

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It is almost trite to say that the entire biota rests squarely upon the twin foundations of soil and moisture, for no kind of life can thrive either in absolutely dry earth or in chemically pure water. It follows, therefore, that all life is dependent upon the mixture in varying proportions of these two essentials. That this

mixture is in turn conditioned to a very considerable degree upon the action, interaction, and reaction of living organisms should be equally obvious.

The animals that live actually in the soil run the whole taxonomic gamut from the Protozoa to the Mammalia, and often occur in such numbers as to defy calculation. One investigator has estimated the weight of the protozoan population of a certain soil to run as high as 500 pounds per acre, with other invertebrates adding 300 pounds per acre to the same soil.

Darwin's work with earthworms is so well known that there would be no excuse to refer to it here were it not likely that it was done so long ago that we have forgotten its present significance. According to Darwin nearly 54,000 earthworms may be found in a single acre, and their burrows may penetrate the subsoil to a depth of 5 or 6 feet. The influence of these animals in increasing the infiltration rate of soils must be tremendous.

Ants and termites exist in incalculable numbers, even in arid regions. Can it be doubted that their tunnels are an important factor in getting into the soil the scanty precipitation that does occur in regions of low rainfall? Examples of invertebrate influences might be cited indefinitely, for nonchordate animals are numbered as the sands of the seashore.

Among the vertebrates, it may well be that even the despised rodent, upon which we have heaped so much of the blame for range denudation accomplished by domestic livestock, more than compensates for its supersurface depredations by its subsurface activity in furthering soil porosity. While rodents have often been charged with actually causing erosion, it is significant that Taylor, who has given considerable study to the question, concludes: "There seems to be little or no evidence of a critical character that rodents or other animals, under natural conditions , promote soil erosion." [1]

If we turn our attention to animal activities above ground, we cannot fail to note the outstanding work of the beaver in both water conservation and flood control. Illustrations are not wanting of serious stream cutting that has followed the extirpation of beavers from certain critical watersheds. Conversely both the Forest Service and the Soil Conservation Service can cite gratifying results achieved through the reintroduction of beavers into certain headwater streams. And, be it said to his credit, at least one of our western field officers detailed his engineers to study the beaver work in his territory—literally sent them to learn upstream engineering from its originators.

My purpose in presenting these brief illustrations is to bring home to you the really tremendous part that animals may play in the conservation of soil and water resources. If we acknowledge their beneficent influence—and we cannot fail to do so—then, it seems to me, we must also accept the definite obligation of considering their rights in our allocation of soil and water resources. Today, wildlife conservation is a topic of everyday discussion, but in actual application we still find a marked degree of disinclination to accord to wildlife the consideration it justly deserves.

Even if our vision is strictly utilitarian we must realize that human welfare and even continued human existence depend in last analysis upon an adequate solution of the basic problem of soil and moisture conservation. How can any solution be adequate that takes no account of the fundamental relations between animals and soils?

[1] Taylor, Walter P., Some Animal Relations to Soils, *Ecology*, XVI, 1935, p. 133.

PART III

In larger perspective

CHAPTER X

Physical and Functional Relationships

BY MORRIS L. COOKE, ADMINISTRATOR
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Upstream engineering is not a new concept. By force of circumstance many other countries have given attention to it, for instance those having territory contiguous to the Alps. Also by force of circumstance we in the United States have given relatively little attention to it. The term is perhaps unusual, but it has the virtue for that very reason of attracting attention to a composite field of engineering for which there has been insufficient regard in the United States.

Not that the field has been entirely neglected. One sector of it—that lying immediately on farms where agricultural operations are conducted—has been given serious study for years past by Federal and State agencies having to do with drainage, irrigation, agricultural practices, and, more recently, soil conservation. Another sector, forestry, has been given noteworthy attention especially during the last 30 years. But these activities generally, because of lack of public interest and insufficient support, have been too limited in scope, have not been sufficiently integrated, have not been related to trunk-stream engineering, and in general have not covered the field adequately.

If we visualize all the waters of a drainage area, we perceive that between the sector where engineers are concerned with farm and forest conditions and problems, and the canalized sector where engineers are in the main concerned with navigation, floods, and power on major rivers, there is an intermediate sector of ponds, creeks, other small streams, and small tributaries, which engineering has not taken actively into consideration. This is because no person or agency has had responsible concern for this neglected sector. Engineering has been kept busy only where there has been responsible concern.

Today there is appearing in some quarters responsible concern for engineering all along the line; from, at the one extreme, the trickle of the raindrops on the farmers' fields, to, at the other extreme, the control of navigation, floods, and reservoirs on main stems. Any novel term therefore renders a service for which we should be grateful if it in the first instance has directed our attention to neglected problems, and secondly has impressed upon us the importance and need of unity in all engineering. The purpose of this paper is to emphasize several aspects of unity; and to urge a far-flung attack on pressing national problems in which engineering in many specialized forms—agricultural, soil conservation, forest, sanitation, small stream, and big stream—are integrated into a single enterprise for the national welfare.

I desire at this time to indicate my own position unequivocally and emphatically. I am convinced that the national welfare—not merely a number of sectional welfares, but the national welfare—is at stake. Obviously, in a conference such as we are now holding, with an attendance representative of all fields of engineering and of all parts of the United States, each affected differently, there are gradations of opinion as to the gravity of erosion and other aspects of the present situation. Every such opinion must be respected, even if not accepted. Those who

desire to see, and who advocate, a spontaneous, democratic organization to carry on an aggressive, far-flung and long-continued fight for correction of conditions will be thought of by some as being self-advertisers, missionaries, and calamity-howlers—as almost anything but safe and sane technical advisers. For myself, I prefer to be alined with the few Shalers who have for many years been predicting exactly what is obviously happening. We may not yet know how to cope with water and land waste problems in all their phases, but we should mark ourselves down as mice rather than as men, were we not to rise to the attack with all the resources at our command, expecting to strengthen our present knowledge in the course of a hard-fought campaign.

It would be a waste of your time to more than recite facts, now familiar to all of us, indicating the seriousness of the problem. The menace to the United States is a complex problem created largely by uses of land and water in many places in a manner not warranted by basic physical conditions. It has various aspects: An appalling rate of soil erosion; minor and major floods; low dry-season stream flow, pollution of lakes and streams; inadequacy of clean water supply; diminution of the ground-water store; and failure to use waters to greater social advantage as they flow to the seas. These matters have for years been set forth in technical reports of permanent Government agencies, and more recently have been clearly and forcibly expounded in general reports of the Land Use Committee and the Water Planning Committee of the National Resources Board, the report of the National Resources Committee on erosion, the report of the Mississippi Valley Committee, and Little Waters, the joint report of several agencies.

Considering these reports and what we have heard during this conference as a background that has established the existence of a menacing factor in our national life, I desire simply to focus attention on the unity in physical and functional relations, and on the necessity of an integrated engineering attack on the soil-water conservation problem.

PHYSICAL UNITIES

A few years ago, outside of highly technical literature, one did not hear much about the hydrologic cycle; young engineering graduates even did not understand its significance. Today a considerable layman audience understands its major characteristics; and more especially, that it is one of the cosmic phenomena having an important bearing on conditions of human life. The layman as a matter of fact is coming to understand it as a phenomenon, in his own words, "having practical significance." The practical significance is that it manifests with unusual clearness a unity of relationships among an unsuspected number of related physical factors, and the necessity of taking all of them into consideration.

There was a time when forestry was considered capable of playing a lone hand in the retardation of run-off. That was because a broad understanding of the hydrologic cycle had not then been realized. Now we are able to approach problems of soil and water control in a more rational manner because we perceive that any one point within the cycle is not a thing by itself, but is related to other points throughout the complete cycle. The direction of the winds relative to some great body of evaporating water and conditions of temperature help to determine whether and how much rain shall fall in certain areas. Water as rain and in expanding frozen form helps to disintegrate rocks and create soils. Or water may create soils by carrying the materials in suspension and depositing them. Characteristics of the soil help to determine the proportions of precipitation that become infiltration and run-off. Soil and water help to create vegetative cover on the land and marine vegetation in the lakes and streams. Vegetation in turn helps to hold soil in place and to retard run-off. Unprotected soils may be carried away

by running water and, according to the way in which it is deposited, influence the direction and character of the stream. These are but a few of the aspects of unity among physical things. Considering man as a physical organism one could include among illustrations the influence of water and soils upon physical man, and his influence on them.

These are very simple matters to most engineers, yet the significance of relationships is not sufficiently emphasized by them for the benefit of laymen, who as individuals and collectively determine in the long run the policies affecting the conservation of land and waters and their uses.

UTILIZATION UNITIES

Out of these relationships among physical factors come relationships among use factors. This is a circumstance of great importance to owners of land and of riparian rights, to engineers, and to those who determine public policy.

One use may promote or it may preclude another. According to differences in local conditions, in one instance flood-control by a system in which retarding dams must predominate, may not permit their use for generation of power; but in another instance a certain proportion of them may be so used. And if we think of headwaters, a considerable number of small dams for the generation of power may be feasible. The more upstream territory we include, the more varied the use relationships within a drainage area. The aggregate of headwaters-control operations in the upper reaches of a drainage area will certainly have collateral use in modifying siltation of reservoirs below; and there is strong presumption that it will influence favorably the flood flow on trunk streams, particularly the strength of normal floods, and very probably the frequency of major and maximum floods by influencing the frequency of the combinations of conditions which cause them. With reasonable certainty it can influence regularity of stream flow and so contribute to the solution of pollution control, fresh water supply and, to a limited extent, navigation problems.

Because of the difference in the nature of physical relationships one cannot imagine circumstances under which trunk-stream engineering works may influence remote headwater conditions. But instances are perceptible in which trunk-stream operations may influence use conditions throughout adjacent tributary backwaters.

The farther upstream one goes in inhabitable terrain, the number of use relationships to be found within a given area is increased. If every acre of an inhabited headwater area is critically analyzed from the viewpoint of best use combined with its protection as a perpetual asset, numerous permutations and combinations of use factors related to physical factors are found. I have seen the plan of a single farm, prepared after such careful analysis, in which definite sections, irregular in shape and size, have been allocated to woods, wood pastures, alfalfa, timothy, ordinary pasture, corn, wheat, oats, and garden stuff; with, in a location convenient to the garden, a pump for supplementary irrigation. This detailed layout of uses was a reflection of the natural lay-out of physical factors, particularly the distribution of soil varieties and slopes both related to dominant conditions of precipitation.

ENGINEERING UNITIES

Of course trunk-stream engineering, in connection with the design of such works as dams and reservoirs, makes as thorough a study as records permit of the precipitation and run-off characteristics of a drainage area involved. In the past, however, these data have generally been brought to bear on the problem of variability of stream flow at the location of the particular work or of each separate section of a comprehensive project. The conditions back in the headwaters area have generally been accepted as indicated by the

data, as acts of God. Such engineering has not yet, except in a few very recent instances, gone far enough to inquire seriously whether numerous acts of man modifying original natural conditions may not be responsible in large measure for the characteristics discovered. Do we actually and always know whether the discovered present characteristics may not be considerably changed by designing in an engineering manner, as an extension of the engineering involved in the trunk-stream works, favorable modifications of acts of man in the headwaters sectors?

One realizes, of course, that engineering design of the scope here suggested is hardly practicable under the conditions under which engineering has been conducted in the past—isolated projects, each project a thing in itself, surrounding conditions to be accepted as is. Drainage areas have not been considered as integral problems, a combination of interrelated units, and the engineering has naturally also not been integrated for the entire area. My present point is that because of interrelations of physical factors, and of physical with use factors, throughout a drainage area, there must be, if the maximum human welfare is our objective, an integration of the engineering of the entire area.

The integrated engineering of an entire drainage area must be made up of many kinds of engineering; civil engineering, agricultural engineering, forest engineering, mechanical engineering, all resting firmly on such sciences as geology, hydrology, geophysics, mechanics, and ecology. Although considered separate fields for convenience in specialization, their relations and unity in respect of the problems of betterment of conditions of living must be recognized, else each will be less constructive—and frequently more destructive of social values—than it otherwise could be. And with respect to works themselves—mechanical manifestations of engineering—there must be variety and unity. A beaverlike retarding dam back on a farm creek and a Boulder Dam on a trunk-stream are parts of the same complex of engineering. Every device of stream control may have a relation to every other device, but all dams do not have to be of concrete with a metal core. Stone, rubble, logs, and litter have each a part to play.

SCOPE OF NECESSARY ACTION

Every organization of a nation for maintenance of its existence is a combination of central and local authorities; in some with major emphasis on central authority; in some with major emphasis on the local. Too frequently emphasis comes to be on division of powers and authority. We must learn to place the emphasis on responsibilities, and on the complementary nature of responsibilities. We must emphasize essential unity at the same time that we utilize separateness for administrative convenience. Otherwise the full value of recognition of physical and utilization unities and of unity in engineering cannot be taken advantage of with maximum benefit.

One of the outstanding advances in the management of industrial enterprises during the past half century has been the shift in emphasis from the concept of departmental independence to the concept of departmental autonomy as part of a coordinated whole. If we are to save our lands and make better use of our waters in the United States we must work out a national procedure which utilizes local autonomy as part of a coordinated national body politic. I take it that the United States is just now feeling its way along these lines. Possibly part of the answer lies in State compacts, possibly in State and regional planning boards, possibly in counterparts of Tennessee Valley Authority. The field for experiment as to governmental devices is inviting.

We must have above all largeness of vision. We must get over what has been called "the disease of distance." In the early days of American participation in the Great War, heads of departments were instructed by the High

Command to attend a meeting addressed by Lord Harnsworth. He announced as the theme of his talk, "The Disease of Distance", and said, as I remember it:

> You Americans are making a mistake to consider the battle front thousands of miles away in Belgium and France. We English at the beginning of the war did the same thing. Even from our island the fighting in western Europe seemed far away. It was only as through telegraph, telephone, and wireless we eliminated this sense of the distant battlefields that we began to get a grip on the situation. We were suffering as you are now from the disease of distance. You Americans must assume that the battle front is in the next room, and come as nearly as you can to making it so by speeding up your lines of communication.

In some such sense our battle against dust-storms, droughts, floods, and especially soil erosion is being retarded. Those of us who live in the North and West have a feeling that, while these things may be just too bad for those who live in the Great Plains drought area, it is almost too far away to mean much. That is not the big view, the proper national view, an entire people's view.

Of course, in all parts of the country we give a thought now and then to the ravages of the agricultural lands of the South which largely because of an undiversified agriculture have to a large extent lost their fertility.

But what we need is that all citizens—North, East, South and West—face the fact that soil erosion is going on over a large part of the cultivated area of our country, and that the variations are chiefly those of the tempo at which the destruction is being effected. No section of the country, of course, can be allowed to be ravished beyond a certain point without the rest of the country suffering thereby. Over and beyond this, however, is the irrefutable fact that within a relatively limited time as the history of nations goes, practically all our plowable lands will be ruined unless in the meantime we learn the technique of defense and apply it.

There are some citizens in every section of the country that have this large perspective. Have you heard any statement of the problem better than that of a recent editorial in the Amarillo (Tex.) Daily News?:[1]

> How big can you dream? Can you visualize flood-control, reforestation, and soil-conservation programs on a big national scale occupying as much attention and thought as a war?

This, in somewhat poetical fashion, poses the question as to the type of organization which will have to be set up to carry on a successful struggle against the inroads on our agricultural well-being now in full cry. It does not seem possible to me that anything short of a far-flung wartime-like organization will be adequate. There should be a general staff including within its membership not only those competent in the fields of management and organization—as in military organization if you like—but also representatives of the wide variety of techniques and disciplines which are already recognized as essential to success.

We shall be well-advised to have in mind that as the campaign progresses entirely new facts will be uncovered, some of them perhaps having a vital bearing on the outcome. It is generally recognized, I believe, that what we know today does not guarantee success. Through research and otherwise we must discover new facts and more effective techniques if we are permanently to arrest soil erosion and reduce flood crests and hold down duststorms to localized areas. The suggestion here is that such an organization[2] should be scaled more broadly than would be warranted by present knowledge. There must

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[1] John McCarty, managing editor.

[2] At the supplementary informal Young Men's Conference on upstream engineering Mr. Cooke stressed the fundamental importance of democratic principles in establishing an organization for conservation. He stated that a democratic organization such as he proposes is an organization in which, perhaps, the Government is the core, and the Federal Government, State governments, local governments and many individuals are affiliated agencies which make the sum total of the effort greater than it could possibly be if we simply relied upon our regular Government machinery.

be provision not only for rapidly increasing personnel but for lines of attack not now in mind.

As one phase in the organization that seems to be required to carry on a successful fight against soil erosion, I suggest that there should be a democratically chosen moderator for every watershed, a moderator for the Mississippi Valley as a whole, a moderator for the valley of the Missouri, a moderator each for the Yellowstone and the Big Horn. It would be better that these appointees should not have any authority in the legal sense, but that they should represent the citizenry of the watershed in advancing the conservation both of water and of soils. If the responsibility of these functionaries could be properly understood their status in the community would be of the very highest, because their opportunities for service would be very great.

It will be fatal to emphasize unduly the military aspect either of this proposed organization or of the impending struggle. Military effort is cited here as the one illustration of where a people puts forth its best talent, as well as its more conspicuous examples of sacrifice. An organization for war means to many people the abandonment of personal and individual interests for the benefit of the whole. But it would be a great mistake to feel that any strictly military organization would be adequate to such a task. This effort will put our democracy and democratic techniques to the full test. There is no way under existing law to say to the millions who own the 2 billion acres of America that they cannot individually and collectively ruin them. At such a point military techniques fall down and only an upsurging of the democratic impulse for the common good can save us.

Surely if we are looking for a moral equivalent for war it can be more than found in a democratically arrived-at determination to pass on the agricultural lands of the Nation to our children in a condition as good as or better than we found them.

DISCUSSION

1. Glen E. Edgerton

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Mr. Cooke has presented his subject in a characteristically thought-provoking and stimulating way—more so, perhaps, than the somewhat prosy title would promise. If, as has been wisely stated, the aspect of a fact depends upon the angle from which you view it, how much more does the purport of a sentence or a thesis depend upon the attitude of the recipients. What I may have to say should, therefore, be regarded tolerantly, both by the author and this audience, as representing merely the reactions created in a mind conditioned in a certain way. It is not improbable that all of the other members of this conference may have received somewhat different impressions from mine and may be impelled to dissimilar response in their own minds.

Take, for illustration, the suggestion that between that sector where engineers are concerned with farm and forest conditions and problems and the river sector where engineers are in the main concerned with navigation, floods, water power, and other developments utilizing structures of large or moderate size, there is an intermediate sector of ponds and creeks which engineering has neglected, until recently, to exploit. That suggestion I can accept without hesitation. My own observation has told me that such a sector exists and that its exploitation has not kept pace with that of the sectors above and below it. However, when the primary reason for this neglect is given as the lack of a person or agency charged with responsibility for this sector, many mental eyes will, I am sure, be unable to refract the image that Mr. Cooke intends to present. Whereever a reasonable return is offered, both engineer and economist are usually quick to recognize the opportunity for investment. Is the neglect of a possible field of exploitation as likely to be due to the lack of a willing agent as to a lack of prospective yield? Those whose minds are

conditioned to give one answer to that question will require evidence that the sector itself is not submarginal in productive character, so far as the yields from engineering construction works are concerned.

The paper emphasizes the importance of soil-erosion prevention, flood control, and water power. Wisely, too, it calls for unified comprehensive treatment of the water problems between the trickle of the raindrops and the mighty rivers they sustain. But unity of treatment need not imply uniformity of development along the path. It implies, rather, a discriminating selection of the points at which the maximum beneficial effect may be obtained with greatest economy of time, effort, and expense.

PHYSICAL AND UTILIZATION UNITIES

The paper properly cites the importance of the several parts of the hydrologic cycle and of the need for its explanation to the public in general. In the consideration of utilization unities, adequate stress is laid upon the desirability of coordination between different uses, but it might be well to point a word of caution against overenthusiasm for multiple uses of particular structures. The determination of the best priorities among several possible conflicting uses is desirable, of course, either specifically for particular works or more generally for particular localities or regions. The design of projects to serve several purposes is commendable when it is practicable and economical, but there is danger that confusion of objectives might produce compromise designs even less efficient and economical than those made without consideration of corollary functions.

ENGINEERING UNITIES

The paper makes an impressive point of the application of engineering to entire drainage areas. It points a criticism of the practice of conducting development project by project without adequate consideration of the needs or possibilities of other projects. Much improvement in this particular has been made in the last decade by the several Federal agencies charged with such activities. The 308 surveys of the Corps of Engineers have provided us with a basic foundation for the planning of works for water control and use on a Nation-wide scale. The extension and elaboration of these surveys, not too far in advance of the probable initiation of actual development work, will forestall for the future such vigorous criticism of past practices. Meanwhile, the study of the best land-use practices and the exploration of the practical possibilities of small headwater developments, and their application and execution, may proceed generally without fear of materially affecting adversely the possibilities of the larger river projects. The surveys and studies authorized in the Flood Control Act of 1936 should permit the preparation of fully coordinated programs in basins where such programs are feasible. The first reports which will be prepared under that legislation, following the appropriation of necessary funds, will be of extraordinary interest to all who may be concerned with the water problem.

SCOPE OF NECESSARY ACTION

The paper is less definitive in its suggestions for organization for the tasks envisioned than in pointing out the objectives to be attained. The reason for this is obvious. It is necessary to propose an organization within the limitations of our form of government, in which a division of legal jurisdiction exists between State and National Governments. Such division is not easily adaptable to the unified aspects which the paper presents so forcefully. It is my own view that although the division between the upstream engineering and downstream engineering is not marked by a definite line, the distinction between them is easy to make. Under our form of government, the one falls pretty clearly within the jurisdiction of the States. It should be stimulated by educational and demonstration programs sponsored by the Federal Government.

The other falls in large part, but not entirely, within the jurisdiction of the Federal Government. It should be supported by State and local interests in proportion to their interest or their capacity to contribute.

I congratulate the author upon this paper. The discursive nature of my own comments is evidence of the success which it attains in stimulating the consideration of varied aspects of the important problems of land and water use.

2. Harlan H. Barrows
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In my opinion most of the major points made by Mr. Cooke are valid and deserve repeated emphasis. Undoubtedly there is general agreement that a given drainage area should be treated as a unit with respect to its water problems; that manifold relationships exist between the natural features and processes within a drainage area, and that these interrelationships have an important bearing on conditions of human life; that the various types of problems associated with the use and control of water and the occupation and utilization of land likewise have complex interrelationships, and that different uses of water or land may be in harmony one with another in some cases and mutually antagonistic in others; that haphazard development and wasteful use of waters and lands have created a situation which is inimical to public interest, and which constitutes a menace to national welfare; and that betterment of conditions will require, among other things, an expansion and integration of engineering.

Mr. Cooke's militant discussion of his last major point, "scope of necessary action", leaves me in a questioning and doubtful state of mind. In order to save the Nation from the destructive consequences of "duststorms, droughts, floods, and especially soil erosion" he proposes a spontaneous organization characterized by a general staff of experts drawn from all relevant fields, including that of military organization, and a so-called moderator for every watershed. By whom would the members of the general staff be chosen? How long would they serve? Would they be employees of the Federal Government or citizens serving gratuitously? What authority, if any, would they have with respect to the moderators? Would the moderators be "chosen democratically", as Mr. Cooke suggests in one place, or be "appointees", as he calls them in another? If they were to be chosen democratically, would they be elected? If so, would difficulties arise from the fact that watersheds do not coincide with civil divisions? If so, further, could it be assumed that they would have the technical knowledge requisite for the proper performance of their duties? What would be their duties? The word moderator (chosen, perhaps, because it is a "novel term", like upstream engineering) throws little or no light on the question. It may refer, as commonly used, to a ruler or governor, an arbitrator or mediator, a temperer or mitigator, or to a presiding officer. Mr. Cooke merely says the moderators "should represent the citizenry of the watersheds in advancing the conservation both of water and of soils." Represent it, where? how? before whom? Is the organization to develop plans for the conservation of water and soils, or to administer plans, or both? Mr. Cooke suggests further that the proposed organization "should be scaled more broadly than would be warranted by present knowledge." How could it be scaled intelligently beyond the limits of existing knowledge? Might it not be better to scale any organization to existing requirements and knowledge, and rescale it later if and when desirable? Mr. Cooke says there must be provision for lines of attack not now in mind, but can anyone really provide for an attack on something unknown to him? It may seem ungracious to ask these questions, and the reply to them may be that the initial proposal of "a spontaneous, democratic organization to carry on an aggressive, far-flung and long-continued fight" should not be expected

to cover details. To my mind, however, these questions do not relate to minutiae. Until they, and many others, have been considered maturely one may be permitted, I think, to regard as premature any action looking toward a new organization of initial magnitude, and one with respect to which Mr. Cooke says there must be provision for a rapidly increasing personnel. Without any such organization, I may add, work of the most democratic kind on coordinated problems of water and land has been undertaken by local bodies in various drainage areas in effective cooperation with existing Federal agencies. There apparently is no evidence that the organizations and procedures involved are proving inadequate.

I trust the task of saving our soils, a matter apparently uppermost in Mr. Cooke's mind, may not prove as long or hard as he assumes. The Soil Conservation Service, to which no reference is made in the paper under discussion, is an organization 10,000 strong that has attacked the problem with great vigor and commendable success. The Forest Service, the Civilian Conservation Corps, and other organizations, both old and new, have been similarly active. Widespread, continuous publicity has been given to their work. The public at last recognizes the need of soil conservation. Both the great political parties dedicate themselves to it in their current platforms.

Mr. Cooke does well, it may be noted again, to stress the great importance of recognizing the numerous interrelationships between physical features and processes and between the various uses, actual or potential, of waters and lands. It would be well to couple with the concept of interrelationships, or "unities", to use his term, the dictum that facts are indispensable prerequisites to sound conclusions with respect to the use and control of natural resources. Conclusions and resultant actions not based on predetermined facts invite and deserve severe criticism, almost certainly involve economic waste, and may preclude appropriate action later in greater or less degree. Too often basic facts and relevant relationships have been ignored. Thus it has been assumed by some that a pond on every farm would solve in large measure the problem of water shortgage in watersheds where the supply of water already is fully appropriated, and in other watersheds where a few reservoirs located, designed, and constructed properly would retain all run-off, whereas numerous ponds would increase greatly the evaporation losses and so reduce the amount of water that might be made available for beneficial use. We have dug ponds where there is no water to be impounded, forgetting that no program for water development can succeed without water. We have dug them where they would constitute a menace to public health and later have filled or drained them. In countless cases, small dams of all types intended to serve diverse purposes have failed because they were designed and constructed in disregard of pertinent facts. Illustrations of many other kinds might be cited in support of the contention that it is unwise to adopt a plan for the conservation and development of the waters of any river basin without a thorough study of adequate data bearing on all phases of the interlocking cultural and physical problems involved. Here, if anywhere, the adage that "haste makes waste" holds good.

Several references are made in the paper under discussion to war and to military organization. They suggest the observation that many pressing problems with respect to waters and lands have resulted in part from the fact that we have waged war on nature. We must now learn to live at peace with her, to cooperate with her, not fight her. We are powerless to change her laws, and it is folly to flout them.

I was impressed by Mr. Cooke's statement that "we must have above all largeness of vision." I agree fully, but at the risk of marking myself down as a mouse rather than as a man, I venture to suggest that while enlarging our vision we should carefully avoid becoming visionaries.

CHAPTER XI

The comprehensive engineering point of view

BY SHERMAN M. WOODWARD, CHIEF WATER CONTROL PLANNING ENGINEER, TENNESSEE VALLEY AUTHORITY, KNOXVILLE, TENN.

THE SCIENCE of soil management occupies a border-line field touching, on one side, the physical sciences of hydrology, climatology, physiography, hydraulics, and agricultural engineering; on another side, the biological sciences relating to ecology and plant growth and production; on a third side, the sciences dealing with the economic and cultural factors involved in human occupation and use of the land. The program of the conference up to this point has been a sufficient demonstration of the complicated and involved nature of the many interrelations between these various sciences. Obviously then, it is most important in planning and executing any ameliorative or improvement measures that we scrutinize all the above-mentioned sciences in order that all pertinent facts may be learned, studied, and given due consideration. At best, in a field as little understood as this, it seems inevitable that many mistakes will be made. By careful study and foresight we may keep the number of these mistakes to a minimum.

The importance of proper soil management for the purpose of restricting as much as possible the harmful effects of soil erosion, and for the purpose of obtaining the highest beneficial utilization of the soil for human needs can scarcely be overestimated. In the few minutes at my disposal I can only hope to review a few of what seem to be the most vital fundamentals necessary to be kept constantly in mind in order to maintain the needed comprehensive engineering point of view.

To give by means of drawings even a general idea of a simple structure requires at least three views: a plan, an elevation, and a cross section. These views do not resemble each other; nevertheless, taken together they represent the whole. A comprehensive view of any program must necessarily take in all sides. It must consider a multiplicity of objectives, some of which may be conflicting. The several views herein presented may at first glance appear to be rather unrelated, but all are a part of the whole.

Of the total annual precipitation which falls on the surface of the ground as rain or snow, only a part ultimately reaches stream courses to flow to the oceans. The run-off in the streams is usually less than half of the total rainfall, often it is much less than half, and for some large areas the run-off is such a small fraction of the rainfall as to be almost negligible.

It is useful to think of the flow in streams as being made up of two portions: First, that part which slowly seeps into the stream from the ground forming the bed and banks of the channel. This part is often called ground-water flow. This flow is generally relatively steady throughout the year. During the low-water season substantially the whole flow of a stream is ground-water flow. Second, that part of the rainfall which reaches stream courses without passing through the soil. This is the part of the stream flow that is subject to great fluctuation. It is large immediately following a heavy rain and dwindles to almost nothing in a long dry time. We have but slight and inadeqate knowledge concerning the relative amounts of the ground-water flow and surface flow composing

our streams, but apparently taking the year as a whole the total ground-water flow and the total surface run-off are about the same size.

That portion of the rainfall which never reaches stream channels escapes back into the atmosphere as water vapor, partly by evaporation from the surface of the wet ground, but chiefly by being taken up in the ground by plant roots whence it is carried upward to the leaves and evaporated from the leaf surfaces. It has been customary on the part of hydrologists to call that portion of the rainfall that does not subsequently appear in the streams, the water losses. This may not seem a logical procedure but this paper follows the established practice of referring to the portion of the rainfall that disappears as evaporation from the soil and transpiration from plants as water losses.

No method exists by which man can control the rainfall. Only very slight human control over ground-water flow can be exercised. Considerable artificial control over surface run-off is possible. The average annual precipitation of the Great Plains area varies between 15 and 20 inches a year. Eastward, it gradually increases to 30 inches in the upper central portion of the Mississippi River Basin, and to 40 inches in the Ohio River Basin. The northeast region has from 35 to 50 inches a year. The South and Southeastern States have from 45 inches on the lower lands to a maximum of 80 inches in the mountains.[1] The precipitation of individual years varies greatly from these averages. In general, the average annual run-off of these different regions varies in much the same way as the precipitation, but the losses of water in evaporation and transpiration are more nearly constant and therefore leave relatively much less water for run-off in the regions of lighter rainfall. The average annual run-off on the Great Plains area varies from 1 to 3 inches. The next region to the east has a run-off of from 3 to 10 inches. The upper central Mississippi River Basin and the Ohio River Basin have from 8 to 20 inches, while that of the northeast region varies from 17 to 25 inches. The run-off of the Southeastern States and the East Gulf States varies from 20 to 30 inches.[2]

Although Weather Bureau records show great variations in the amount of precipitation from year to year in all parts of the United States, authorities generally agree that there are in different regions cycles of wet years and cycles of dry years extending over varying periods of time, and that our records of precipitation are too brief to show any definite change in climate or that man's activities have had any effect on the amount and distribution of precipitation.

Between one and two million acre-feet of water a year is at present passing into the air in Imperial Valley, California. Before irrigation began there some 30 years ago, no such evaporation existed, but there is no evidence that the climate has been changed.

The history of the settlement of the semiarid regions of the Great Plains during the past 75 years has been one of advancing and receding waves of migration, depending on the cycles of wet and dry years.

Since nothing can be done to change the amount of water falling on the land, attention must be directed in semiarid regions to increasing, if possible, the amount of water that will soak into the ground and decreasing the losses due to direct evaporation from the land. Mr. A. F. Meyer, on page 389 of his text on hydrology, states: "If the level of saturation is about 20 feet below the surface of the ground in clay subsoils, and about 10 feet in sandy subsoils, and if the watershed is free from matured forest cover, the ground water is safe against evaporation and transpiration loss. The best ground-water supply is found in regions of ample precipitation where both soil and subsoil are of fine sandy character and forest cover is absent."

[1] *Atlas of American Agriculture*, U. S. Weather Bureau.

[2] From: Map by Henry Gannett from Data of U. S. Geological Survey.

He further points out that shallow warm-water lakes have a relatively larger evaporation than deep cold ones.

Observations by the Geological Survey [3] show that ground-water levels of the Platte River Valley in the Great Plains area have declined in the last few years concurrently with the deficiency of precipitation, which, between July 1932, and the end of 1934, amounted to 22 inches—a deficiency equivalent to about 1 year's normal precipitation. It may reasonably be expected that future years of greater precipitation again will raise the ground-water levels. Evaporation and transpiration studies have shown that during the growing season the losses from evaporation are greater from open water surfaces than from bare cultivated soils. In the growing season, the combined effect of soil surface evaporation under a forest cover, plus the direct evaporation from the trees, plus transpiration losses, exceed the direct evaporation from open-water surfaces by about 50 percent.[4]

The water which runs in the streams is made up of two parts: Surface run-off, which flows directly over the surface of the land into the stream channel; and underground flow, which reaches the stream channel by seeping through the soil. Surface run-off is flashy in character and continues only during time of precipitation or for a very brief time afterward. Underground flow travels but 1 or 2 miles a year in average soils and 4 or 5 miles a year in gravel and, therefore, is distributed throughout the year. Records of run-off have been kept for many years by the United States Geological Survey of the Department of the Interior on most of the streams of the United States. In Water Supply Paper No. 772, published in 1936, the results are given of comparative studies of precipitation and run-off on seven representative streams in the eastern United States. A portion of the results for these streams is summarized in tables 15 and 16. These show an average annual precipitation on the Red River of the North above Grand Forks, N. Dak., of 20.91 inches and an average annual run-off of 1.25 inches for the period 1882–1934. In the southeast region, the Tennessee River Basin above Chattanooga in the period 1881–1934 had an annual precipitation of 50.36 inches and a run-off of 24.24 inches.

A comparison of the 10-year average precipitation and the 10-year average run-off was made by the Geological Survey for each of the streams mentioned in the tabulation for the entire

[3] *Rainfall and run-off in the United States,* U. S. G. S. Water-Supply Paper 772, p. 273.

[4] D. W. Mead, *Hydrology,* p. 147.

TABLE 15.—*Relation between mean annual precipitation and run-off on streams in Eastern United States*

Basin	Period of record	Average Annual			Maximum annual run-off	Year	Precipitation annual [2]	Water losses, annual [1,2]	Minimum annual run-off	Year	Precipitation annual [2]	Water losses, annual [1,2]
		Precipitation	Run-off	Water losses [1]								
		Inches	*Inches*	*Inches*	*Inches*		*Inches*	*Inches*	*Inches*		*Inches*	*Inches*
Red River above Grand Forks, N. Dak.	1882–1934	20.91	1.25	19.66	3.12	1897	27.76	24.54	0.13	1934	14.67	14.54
Mississippi River above Keokuk, Iowa	1878–1934	29.51	6.98	22.53	13.19	1881	41.28	28.09	3.12	1934	26.57	23.45
Neosha River above Topeka, Kans.	1896–1934	33.57	4.12	29.45	12.40	1903	40.78	28.38	1.04	1934	26.76	25.72
Merrimack River above Lawrence Mass.	1880–1934	41.63	20.13	21.50	31.54	1928	51.48	19.94	10.65	1911	32.96	22.41
James River above Cartersville, Va.	1899–1934	40.79	15.59	25.20	25.06	1901	54.03	28.97	7.00	1931	21.16	14.16
Tennessee River above Chattanooga, Tenn.	1881–1934	50.36	24.24	26.12	34.12	1882	64.10	29.98	19.98	1931	44.37	24.39
Chattahoochee River above West Point, Ga.	1897–1934	54.59	22.32	32.27	37.61	1929	78.46	40.85	11.57	1904	36.03	24.46
									12.71	1931	45.75	33.04

[1] Precipitation minus run-off.

[2] Precipitation and water losses for corresponding year.

period covered by the records. This study disclosed a rather decided tendency for a somewhat smaller run-off for a given amount of precipitation during the latter half of the period than during the first half. On page 110 of Water Supply Paper 772 the following statement is made:

Changes are supposed to have resulted from man's occupancy. The change in the relations by which less annual run-off has come from the same amount of annual precipitation appears, however, to be somewhat at variance with the opinion frequently expressed. The question arises whether cultivation has not accomplished conservation of moisture for crop production in amount sufficient to overweigh any increased surface run-off that might have been occasioned as a result of agricultural and other activities of man.

TABLE 16.—*Relation of precipitation to surface run-off*

Basin	Period of record	Average annual—				Percent of precipitation in surface run-off
		Precipitation	Run-off	Ground water run-off	Run-off	
Red River	1928–32	18.53	0.59	0.24	0.35	1.8
Mississippi	1928–32	28.64	5.96	2.62	3.34	11.7
Neosha	1928–32	33.07	4.90	0.85	4.05	12.3
Merrimack	1928–32	40.66	19.55	9.59	9.96	24.3
James	1928–32	38.04	13.12	6.09	7.03	18.5
Tennessee	1928–32	49.83	23.70	8.44	15.26	30.5
Chattahoochee	1901–05	59.65	23.10	11.55	11.55	19.3

The decrease in run-off corresponds to increase in water losses by surface evaporation and transpiration. On the Tennessee River Basin above Chattanooga for the 10-year period from 1885 to 1894, with 49.32 inches of precipitation the water losses were 23.63 inches. For the last 10-year period of the record, from 1925 to 1934, with 49.09 inches, or almost identical precipitation, the water losses were 28.48 inches, or nearly 5 inches greater than in the first period. Other 10-year comparisons show similar evidence of a progressive increase in water losses.

In Water Supply Paper No. 772 an estimate is made of the underground flow which appears in these same representative streams. This deducted from the total annual run-off leaves the surface run-off, representing roughly the amount of water that generally is considered as uncontrolled. The tabulation in table 16 shows that for the period 1928–32 the average annual surface run-off from the Red River Basin above Grand Forks was 0.35 inch. For the same period, the surface run-off from the Tennessee River Basin above Chattanooga averaged 15.26 inches. These amounts represent roughly the opportunities for the storage and regulation of surface run-off.

The popular impression that floods are greater and more frequent than formerly is doubtless based in part on the visible evidence of greater destruction caused by floods in highly developed territory as compared to flood destruction under primitive conditions. Flood records on the River Rhine in Europe, starting in 1770, show floods in 1784, 1799, 1809, 1814, and 1855 almost as great as the record flood of 1862. The greatest flood of record on the River Seine at Paris was in 1615, the next greatest in 1658. Others occurred in 1649, 1651, and 1740. Two of these exceeded the great flood of 1900. The study made by Mr. Ernest Landa, Chief of the Hydrographic Bureau of Austria, of flood records on the Danube River, starting in 1012, showed that the great floods of 1897 and 1899 were not unusual or abnormal.

The Connecticut River experienced great floods in 1801, 1843, 1853, 1862, 1869, and 1895, as well as in 1936. The greatest flood on the Mississippi River at St. Louis was in 1844, with floods next in order of magnitude in 1785, 1828, 1855, 1826, and 1858. The Missouri River flood of 1844 at Kansas City exceeded all others of record, with floods of 1903, 1908, 1881, and 1916 next in size.[5]

Great floods are caused by unusually heavy precipitation occurring in a series of storms pass-

[5] Data from *Hydrology* by D. W. Mead, pp. 569–574.

ing over a river basin, the first of which saturates the ground so that the later storms are converted almost entirely into run-off, or by a single great storm which continues long enough to saturate the ground and convert its later stages all into run-off.

Single storms which produce rates of precipitation so high as to prevent the ground, despite its absorptive capacity, from absorbing an appreciable part of the water give rise to very high rates of run-off. Frozen soil and melting snow act to augment run-off from rainfall.

On May 21, 1936, an Assistant Chief of the United States Forest Service stated to the Committee on Flood Control of the House of Representatives: "The Forest Service of the Department of Agriculture does not contend that forests are a complete remedy for floods. We know that at times throughout a wide region there occur a combination of conditions, such as deeply frozen ground and a heavy blanket of snow and quick-rising temperatures and heavy spring rains, and in such circumstances nothing you can do will prevent the torrential and destructive run-off." [6]

In planning flood-control works such as levees and storage and detention reservoirs, provision must be made for the greatest flood reasonably to be expected, with safeguards such as spillways and other relief works to protect the integrity of the flood-control works under any conceivable conditions. Otherwise, failure of the works themselves will bring greater destruction than if no work had been done. This principle must apply whether the stream controlled be large or small. Changes in cultural methods which may decrease the surface run-off by increasing infiltration and evaporation and transpiration losses from moderate or even large storms will not reduce the cost of flood control works which must be built to withstand the attack of the greatest floods.

Recently the Geological Survey of the Department of the Interior published the results of an exhaustive study [7] of the existing data on floods in the United States. One of the typical river basins studied was the Tennessee River above Chattanooga, Tenn. The period studied extended from 1874 to 1933, inclusive. The results of this study given on pages 441–448 are as follows:

> The minimum magnitude for general winter floods has been taken at 112,000 second-feet. For the first 30-year period the total number of winter floods is 106 and the average flood 178,700 second-feet. For the second 30-year period the total number of winter floods is 87, and the average flood 158,000 second-feet.
>
> If, however, floods of over 200,000 second-feet, which may be regarded as major floods, are considered the first 30-year period contained 32 such floods, and the second only 10.
>
> The average date of winter floods of 200,000 second-feet or more was March 1 in the first half of the record and February 17, or 12 days earlier, in the second half.
>
> The figures suggest the possibility of a systematic change in hydrologic conditions, which has decreased the tendency to production of extremely high floods since about 1904 and has set back the occurrence of the higher floods by 12 days.
>
> The data and the statistical analysis indicate the possibility of a change in conditions in the Tennessee drainage basin which has brought about a decrease in magnitude and frequency of measured floods, has resulted in making earlier by 12 days the average date of major floods, and has materially increased the water losses from the drainage basin. In this case, as in others where the results of statistical analyses may be affected by changes in conditions, it is desirable not only to determine the effect but, if possible, to determine whether an adequate cause can be found.
>
> The observed changes in hydrologic conditions may be the result of changes in meteorologic conditions, or changes in topographic or cultural conditions.

The report indicates that changes in rainfall and temperature during the period studied are not sufficient to account for the changes in floods. Commenting on change in cultural conditions, the report states:

> Exhaustive study of the history of deforestation in the Tennessee drainage basin has not been made. However, from general knowledge and information readily available it appears that unquestionably extensive deforest-

[6] H. R. 12517, 74th Cong., 2d sess., p. 7.

[7] *Floods in the United States, Magnitude and Frequency.* U. S. Geological Survey Water Supply Paper 771.

ation took place in this basin beginning about 1890 and continuing into the second half of the period of record. In some places this deforestation was partial, the smaller growths being left standing; in others it was followed by clearing and cultivation and the growth of crops, such as corn.

This raises the interesting question, What, if any, effect may the cutting of timber in this drainage basin have had on water losses and flood magnitudes? Deforestation might either increase or decrease water losses, the effect depending in part on the kind of vegetation, if any, that replaced the forest.

Flood magnitudes, particularly for summer floods, are highly sensitive to changes of infiltration capacity of the soil * * *. Infiltration capacities vary over a wide range on different areas and under different conditions, particularly in summer.

Evidence of lack of change in summer flood frequencies and magnitudes on the Tennessee River drainage basin indicates, so far as it goes, that there has been no important change of the infiltration capacity as between the two periods considered.

An assumption that deforestation is partly the cause of a decrease in flood magnitude in the Tennessee drainage basin is therefore consistent with the findings resulting from the statistical analysis.

Domestic water supply from surface run-off has been used since the dawn of history. Homer, in Book 7 of the Odyssey, describes the waterworks which engineers of that time had constructed to serve the gardens of Alcinous and the adjacent town.

Carefully written descriptions of the waterworks of the Roman era and remains of magnificent arches and other works near Rome and elsewhere in former Roman provinces prove the great ability of the waterworks engineers of that period. London obtained water from the River Lea through works constructed in 1609 to 1613 by Sir Hugh Middleton. Boston in 1796 was supplied with water by gravity from Jamaica Pond, situated a short distance outside the city limits.

For many years engineers connected with municipal water supplies have been keeping accurate and complete records of the run-off from small areas used as the source of such supplies. Such records are older than most similar records in large areas. A few of the better known studies on small areas will be mentioned.

Benjamin S. Church, an engineer employed by the city of New York, made a study of surface water supplies for the Croton waterworks and reported in detail in 1876. In a paper prepared by Mr. Allen Hazen and published in the Transactions of the American Society of Civil Engineers in 1914, entitled "Storage to be Provided in Impounding Reservoirs for Municipal Water Supply", rainfall and run-off records are included for a number of eastern rivers. For the Croton River, supplying water to New York, the records studied began in 1869. On the Sudbury River, which supplies Boston, the record studied began in 1875. On the Pequannock, supplying Newark, N. J., the record began in 1892. Three creeks supplying Philadelphia have been studied since 1890. On Gunpowder River, supplying Baltimore, there are records of run-off since 1883. The Massachusetts State Board of Health reported on evaporation studies in 1890. Arthur T. Stafford made a detailed report on Fall River, Mass., water supply in 1902. The Connecticut State Department of Health has made surface-water-yield estimates of every public water supply in the State, because most of the Connecticut population is dependent on surface water supply. Measures which increase the run-off are beneficial to this type of municipal water supply. Cultural methods which increase the evaporation and transpiration losses are harmful.

Many small dams have been built throughout the country by farmers and others interested in impounding small quantities of water, often without engineering designs or plans and without any provision for spilling the water should the dam be overtopped. Failures have occurred and often such dams were not restored after their failure, because the cost of adequate spillway structures on small dams was beyond the means of the interested parties.

In 1917 a bulletin on Farm Reservoirs was

issued by the Bureau of Agricultural Engineering. Subsequently, instructions by the same agency have been issued covering small dams for control of gullies. The Bureau of Agricultural Engineering, the Soil Conservation Service, the Geological Survey, the Forest Service, the Indian Service, and the National Park Service are now cooperating to standardize instructions for small dam construction by compiling a Federal Manual on Design and Construction of Small Dams.

The Kansas water storage law enacted in 1929, amended in 1933 and 1935, provides for State engineering supervision of private dam construction on dry watercourses, defined by the law, and as an inducement to such construction the owner of the contiguous land is allowed a reduction in the assessed value of the land for taxing purposes, the amount of such reduction amounting to $40 for each acre-foot of storage afforded up to 40 percent of the previous assessed valuation of the entire tract. Regulations and instructions covering such dam construction have been issued by the Division of Water Resources, Kansas State Board of Agriculture.

In general, the cost per acre-foot for storing water in small reservoirs is much greater than in large reservoirs. On drainage areas in the Tennessee River Valley varying in size from 20 to 80 square miles, where exceptionally favorable dam locations have been investigated, the cost of storage ranged from $25 to $65 per acre-foot. The cost of storage in the large Norris Reservoir is about $8 per acre-foot. On certain very small areas drained by brooks, the cost of storage provided has varied from about $300 to $600 per acre-foot of capacity. On individual fields, farm terraces, a kind of storage dam may be provided at a cost of from $100 to $150 per acre-foot of storage capacity.

In many parts of the country the existing highway and railroad embankments offer some opportunity for storage of moderate amounts of surface water by means of constructing a raised concrete weir acting as an inlet to the upper end of culverts or pipes under such embankments.

In malaria districts the impounding of water without intensive and expensive measures for control of malaria-carrying mosquitoes has resulted in explosive outbreaks of malaria. Furthermore, unregulated impounding of water has brought malaria to new localities and brought a return of malaria to areas free from it for generations. A map prepared by Francis A. Walker from the returns of mortality for the Ninth Census of the United States, in 1870, shows malaria to have been prevalent over a large part of the United States east of the Great Plains. Sixty years later the area where malaria was prevalent was much reduced and was confined almost entirely to the Southern States.

J. A. LePrince, senior sanitary engineer, United States Public Health Service, Memphis, Tenn., stated to the spring meeting of the American Society of Engineers in 1936: "The statistical abstract of the United States reports about 5,000 deaths from malaria in 1933, corresponding to 1,000,000 cases of malaria, mostly in the South. Since then malaria has been decidedly on the increase in the South. In some States the sick rate doubled in the last 3 years. In a recent school survey blood smears from 150,000 children were taken, and 5 percent were positive. In a few schools the rate was 95 percent." Paul S. Fox, public health engineer, State Bureau of Public Health, New Mexico, reports that malaria was first noted there in 1927 adjacent to water confined in highway borrow pits and irrigation systems. During the past 2 years in that State an average of 600 men has been used in 11 counties in eliminating mosquito breeding places by getting rid of impounded water. At Cookeville, Tenn., a municipal hydroelectric plant was built on Falling Water River without preparation of the area to be flooded and with no provision for control of mosquito production. Filling of the reservoir was followed by a severe epidemic of malaria, with almost universal infection of the resident population, although the disease had been unknown

in the region for many years. At Gantt, Ala., a reservoir was filled without preparation and without provision for mosquito control. There immediately followed the development of 200 cases of malaria within a mile of the shoreline. The State department of health required that the reservoir be emptied, the basin cleared, and control measures put into effect.

In 1936, Tennessee put into effect regulations covering all impounded waters except those smaller than 1 acre, used exclusively for stock watering or other domestic purposes. The application for permit to impound water must give a detailed description of the proposed work, particularly the maximum and minimum water levels. During construction, the State requires that employees infected with malaria may not be brought on the construction work from other localities. All vegetation must be cleared from the area to be inundated. The regulations require that the water be fluctuated periodically at relatively short intervals. They require the removal of all flotage, the removal of all aquatic growth, and the application of larvicides if found necessary. Screening of closely adjacent houses may be required. Tennessee regulations do not permit a reservoir to be filled between April 1 and September 30. Inspection is required at all times, and permits are subject to revocation. Other States having similar regulations governing the impounding of water are Alabama, Georgia, Florida, North and South Carolina, and Virginia.

The cost of mosquito control on large reservoirs is expensive even though weekly fluctuation of the water level greatly reduces the breeding of the malaria mosquito. Oil spraying on shorelines is necessary at frequent intervals. Broad, shallow areas of water very often grow up with aquatic vegetation, frequently requiring airplane dusting with larvicides each week during the mosquito-breeding season. In small reservoirs the cost of mosquito control is more per acre-foot of storage than in large ones, because of the greater proportion of shoreline and shallow water and the difficulty of organizing and maintaining a trained patrol for small widely scattered reservoirs. The water supply to small reservoirs, furthermore, is not sufficient to provide the necessary fluctuations in water levels. The cost of malaria control is the largest item of annual expense in the operation of water-control projects of the Tennessee Valley Authority. Health regulations in Tennessee do not permit the impounding of water between April 1 and September 30 in small reservoirs which might have gone dry during seasons of deficient precipitation. This limitation on small reservoirs seriously affects their usefulness.

Destructive water erosion of soil to a greater or less degree extends throughout the country. A large part of the soil particles moved by erosion is soon redeposited, but the great rivers continue to carry vast amounts of fertile silt to the sea. The Indian name "Missouri" signified muddy water, and the white man agreed with him by calling the river "Big Muddy". The amount of fine silt the Mississippi River alone carried to the Gulf of Mexico is staggering. Capt. A. A. Humphreys and Lt. H. L. Abbott were intrusted in 1850 with the monumental task of making a survey and report on the physics and hydraulics of this river. The investigation continued for years, and their voluminous report to the War Department in 1861 has long been regarded by engineers as a classic. It gives the results of years of observation on the silt carried by the Mississippi. They estimated that the amount of silt carried and rolled by the river to the Gulf each year would cover 1 square mile to a depth of 315 feet.

Cultivation methods and types of crops are dominant factors in the control of soil erosion. Contour plowing and strip cropping have been successfully used in a small way for a long time, but their use should be extended promptly to additional millions of cultivated acres. The useful life of steep cultivated slopes can be prolonged by a combination of all the soil-saving devices, but continued cultivation means

ultimate destruction. The only salvation for the soil in such situations is to substitute crops that do not require inter-tilling. Existing rainfall and run-off records fail to indicate that cultivation methods have had any effect on great floods. Studies of the effect of cultural methods on run-off are being continued on both large and small areas in many parts of the United States.

Small reservoirs scattered on the small streams can control floods only when their combined useful capacity equals or exceeds that required for large reservoirs on the main streams. Small reservoirs on the headwaters of river systems afford no control for the large amounts of downstream run-off. The proper timing of the emptying and filling of a multitude of small reservoirs to control floods at distant points during successive storms sweeping over a great river system is beyond human limitations. The failure of one small dam, cheaply constructed and inadequately safeguarded, on the headwaters of a small stream might start a succession of failures on similar dams immediately downstream with resulting greatly aggravated flood conditions. The cost of adequate flood control by means of small reservoirs would be many times that of a relatively small number of larger reservoirs on main streams and principal tributaries.

Small reservoirs do not in any way prevent sheet erosion better than large ones; the former trap only a part of the soil torn from the adjacent hillsides by erosion. Even the farm terrace, a kind of dam, only reduces sheet erosion by partially controlling the direction of the run-off and acting as a check dam to catch a part of the silt eroded from the field immediately above. Farm terraces, unless properly constructed and perpetually maintained, fail during times of heavy rainfall and cause great local erosion. Outlets to farm terraces, frequently poorly protected and maintained, are an all too prevalent cause of great gullies.

When soil is loosened by sheet erosion, the heavier particles are deposited at the first considerable reduction in velocity of the flowing water. The very finest particles are carried in suspension, deposited only when the water is completely checked. Heavier particles are dropped at the foot of hillsides. Consequently, dams on small streams receive silt deposits at a greater rate per square mile of watershed area than dams on large watershed areas. The useful life of small dams is short compared to large dams. Measurements made by the Soil Conservation Service in 1934 and 1935 in reservoirs in the Southeastern States show an annual silt accumulation of 2 acre-feet per square mile of drainage area in a reservoir having a drainage area of 5 square miles, a rate of 1 acre-foot per square mile in a reservoir having a drainage area of 10 square miles, and rates as low as one-quarter acre-foot in reservoirs with drainage areas of 100 square miles and upwards. The variation in rate of annual silt accumulation between reservoirs on large and small streams in the Southwestern States is greater. A reservoir with a drainage area of 1 square mile had an annual silt accumulation of 5.5 acre-feet a year. Reservoirs with drainage areas of 10 square miles had a rate of about 2.25 acre-feet; those of 100 square miles about 1.5 acre-feet.

Having covered briefly some of the fundamental aspects of the water-control problem, it is necessary in conclusion, only to complete our statement by saying that the comprehensive engineering point of view seems to require three things:

First, that we obtain in every case all the pertinent scientific facts bearing on a problem, gleaning these facts from the science of agriculture, the pure sciences, the profession of engineering, or wherever they may be found.

Second, that we use our utmost endeavors to supplement our entirely inadequate existing knowledge by making further studies, investigations, and researches wherever possible in order to remedy the obvious deficiencies in the data needed for the best solution of the problems that confront us.

Third, that in applying our knowledge and skill to the solution of a specific problem we use the greatest care in selecting, from the many possible methods of attack, that particular method which, in the light of all our knowledge and previous experience, offers the most promise of leading to a successful solution. When we look back upon the history of our recent depression and all the measures that were proposed for its relief, it is apparent that not 1 in 10 of the proposed remedies had real merit. In approaching any unusual human problem it seems peculiarly difficult to divest ourselves of prejudice and preconceived notions as to the best solution, to maintain an objective point of view, and to preserve an unbaised and judicial attitude towards the evidence adduced. Perhaps the greatest menace confronting society today is the difficulty of distinguishing between true and false leadership. We should be careful in maintaining a suspended judgment until the reasonably available evidence is in, and in taking every care that any advice that we give is unbiased, unprejudiced, and is strictly in accord with carefully established facts.

DISCUSSION

1. Walter C. Lowdermilk

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Professor Woodward has raised a question which calls for a few remarks in view of a long-standing controversy. This problem of the role of vegetation on stream and flood flow has been a matter of special interest to me for more than 15 years and I have taken occasion to read a great amount of literature upon this subject. A summary of the literature, going back to 1844 is included in a document entitled "Forest and Agricultural Influences in Streamflow and Erosion Control." [8]

This controversy began with Wex and Valles. The work of Gustav Wex (1873), the Counselor of State and Director of Works for the improvement of the Danube River, ascribed the recorded diminution of water in wells and streams to the clearing of forests within the basin of the Danube. Shortly thereafter Belgrand and Valles in France found no record of reduction in flood stages on the Seine at Paris as a result of the progressive clearing of the basin of the Seine of forests and cultivation to agricutural crops since the Middle Ages. Accordingly, these observers disagreed with the conclusions of Wex. This disagreement on the effects of forests or of their absence on floods began the long controversy which has not yet been fully settled. It has been my purpose to discover the reason for the discrepancies in the conclusions of the students of this problem throughout the literature. Treatment of this subject has often given rise to heated discussions. In this document referred to I have attempted to review the works of all the important investigators and to place the conclusions for, and the conclusions against, side by side and to ascertain why contrary conclusions were reached.

To this end, the problem of the role of vegetation on the hydrologic cycle was re-analyzed with a view of isolating the salient factors involved. And then, experiments were planned and carried out to evaluate these factors. The task has only been partially completed; but sufficient has been discovered in the Berkeley experiments to clarify some of the difficulties encountered by students in the past.

Two important conditions are involved in flood flows; one, the factors which determine the intake and temporary storage of precipitation waters in the soils and underlying rock; sometimes called the factors of retention. It must be realized that the access to the storage in underground rock is through the soil layer. Conditions in the soil which determine the rate and quantity of intake will govern the delivery of precipitation water to underground geological structures. It must also be recognized that the

[8] Mimeographed. U. S. Department of Agriculture Soil Conservation Service.

soil and underlying rock represent the greatest of all storage reservoirs excepting the oceans. The second important condition involves the possibility of synchronization of flood-contributing conditions, sometimes called, synchronization of factors. The flood-control engineer must design for these possible combinations of conditions which contribute to flood stages. It is important, therefore, that an approach to the flood-control problem recognize these two major aspects of the problem.

The Berkeley experiments demonstrate that forest or other natural vegetation as a medium of absorption of precipitation water is negligible in comparison with its effect in determining the rate of intake of water into a soil. The natural cover of vegetation permits the soil and underground rock to function to its capacity in the absorption of storm water. No more can be expected than this. Numerous studies on erosion and run-off have demonstrated beyond question that the clearing of land increases the rate of surficial run-off and of storm flow. And it would be expected that such a result would occur over an entire drainage which had been cleared and cultivated. Accordingly, the treatment of the land so as to favor or disfavor the intake of precipitation waters should be an important factor in all plans for flood control.

The failure, however, of many students of flood problems to find such marked differences in run-off from large streams has cast doubt upon the influence of the condition of the land surface of the drainage area on flood flows. The reason for this, in my opinion, is very important and has been overlooked. It is, namely, that the variable area within a drainage contributing to storm run-off and flood flow masks the effects of surface condition on flood flows in the major stream. The larger the drainage area the more will such effects be masked. Thus, it becomes impossible to measure in the flow of a large stream the progressive effects of clearing and cultivation within its drainage area. In time, however, accumulation of erosional debris within stream channels will reflect conditions of accelerated run-off of former years. It is further possible for both run-off and erosion conditions to develop to stages of serious damage to the land without corresponding response in discharge in the major streams, until the sorted erosional debris gradually fill up drainage channels.

Withal there still remains the problem for the flood-control engineer to design for possible maximum flood flows. Since he must design for a combination of conditions, it will not be advisable for him to assume that measures of erosion control and water retardation, while as a general rule will reduce flood stages, will on the other hand prevent the combination of flood contributing conditions. He should, however, also recognize that erosion control and the reduction of flash flows will safeguard the longevity of and investments in downstream engineering works.

2. C. S. Jarvis

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Throughout the sessions of this conference, there have been references to some elements of physical and functional relationships which deserve further notice at this time, with a view to reconciliation of outstanding differences. My particular comments refer to remarks, statements, or references relating to small storage projects, which were evidently calculated to discourage or reduce their inclusion in future programs. These comments seem to be in order regarding the physical and functional relationships of small reservoirs and their adaptability to serve several purposes.

Among the objections urged by various speakers against the development of small storage reservoirs are such considerations as high construction costs per acre-foot; wasteful rates of evaporation, and loss by percolation into the subsoil; or, where infiltration is most desired, it

has been intimated that the fine sedimentary deposits would effectively seal the reservoir bottom. And, finally, it was charged that a full reservoir is of no value in the control of floods, just as an empty reservoir is ineffective as a conservation measure; that a multi-purpose reservoir is but a compromise reducing its value for its principal purpose in order to accommodate other uses.

There are situations where small reservoir storage competes successfully with larger projects even in unit costs, notably where the deepening of a natural lake or swamp outlet, the installation of a headgate, and the raising of the rim by diking, increase its controlled storage capacity. For small storage reservoirs equipped with open spillways at elevations representing two-thirds of the allowable storage depth, for example, spillway at 20 feet and maximum flow line at 30-foot elevation, the volume below the spillway crest is considerably less than that above; computed by the conical formula, it is 30 percent, or by the wedge formula, 44 percent of the total volume under the high water contour. Generally, the actual volume is somewhere between that of a cone and that of a wedge. For average conditions, then, with such reservoirs, about three-eighths of the total volume is below the spillway, while five-eighths is above spillway crest and thus subject to automatic release as the flood subsides.

If the spillway crest is lowered or deepened by a notch to one-half the total storage depth, then the permanent storage according to the conical formula is 10 percent, and by the wedge formula, 25 percent of the total, leaving, for average conditions, about five-sixths of the total storage for automatic release and flood regulation. It is thus apparent that one-half or two-thirds or more of the available power head may be utilized, while five-sixths to five-eighths of the flood control capacity remains available. Wherever it proves advisable to install flash boards on the spillway crest, with either manual or automatic control, and to arrange for drawdown in accordance with storm and flood forecasts, the benefits to water conservation, utilization, and flood control may be proportionately increased.

Now as to sedimentation and infiltration: Did you ever see a reservoir made entirely impervious along its upper contours? At and above ordinary spillway level, you may ordinarily depend upon continuous infiltration into the soil, coincident with the surplus flow or storage. Below spillway level, the fine sediments tend to seal the reservoir bottom, thus insuring the retention of the last fraction of storage volume as long as practicable, while the exposed area of water surface becomes less and less, thus reducing evaporation losses.

The conservation of water through reservoir storage is not to be measured entirely by the exposed volume; a part of it passes by infiltration to the underground reserve. Having seen many a reservoir dry at certain seasons of the year, after they had fully justified the cost of their construction and maintenance by carrying over, for a few weeks or months, the flood waters for irrigation, livestock watering, and other farm purposes, I cannot subscribe to the suggestion that a dry pond or reservoir is necessarily a hydrologic failure. Even though it performs up to expectations only 9 years out of 10, or 4 out of 5, it may be a successful project. Indeed, a detention or storage reservoir that is too frequently overtaxed is probably on the brink of destruction. The occasional retention of some portion of the flood crest fulfills and justifies the original purpose of such a structure. The necessity for preventive measures against sedimentation results in improved land use and thereby in benefits to both soil and water conservation, and in protection of other reservoirs downstream.

Small reservoirs properly located and automatically operated through adequate spillways, judiciously placed, may serve the major portions of several purposes, including flood control, water and soil conservation, sanitation, recreation, wildlife habitat, power development, and maintenance of ground water, without serious impairment of any of these functions. Further-

more, such benefits are to be realized either successively or cumulatively by other similar projects downstream.

It would be difficult to convince a landowner that he should forego the development and use of a small water power and storage site upon his farm because of the lower storage costs in some community enterprise several miles downstream. The convenience of having water supply for livestock, fire protection, irrigation, and small power purposes (even though operation be seasonal), within his farm boundaries should offset a considerable difference in storage cost per acre foot. And paradoxical as it may appear, the value of a community reservoir and power project downstream would be enhanced and its capacity maintained by the smaller reservoir projects on tributaries. The broadest fields and most numerous opportunities in upstream engineering must have some relation to such small storage enterprises.

3. R. U. Blasingame

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The writer believes that upstream engineering, i. e., the control of headwater streams and of infiltration and run-off, is supplementary to big waters control and that both must be considered in any comprehensive plan of engineering designed to conserve water and soil and control floods. The engineering profession needs to realize the social significance of its work and further to appreciate the fact that many small and relatively insignificant engineering projects, when properly developed in the aggregate may be as potent measures for the control of natural forces as one mighty achievement which may only inadequately serve the purpose for which it was planned.

There is great value in cautious leadership. However, this is a dynamic world, and by being a dynamic world it continuously imposes problems which are largely the result of our own conduct. Therefore, the solution of such difficulties lies in the modification of our conduct which causes those problems. We must solve them and not let them go by default. We must use the science at our command, but must not wait or hesitate because there are prospects of more science to come. We must take some risks and thereby may make some mistakes, but they can be minimized in the light of the scientific knowledge now at our command by such conferences as this one. Action and risk which mean experiments are themselves laboratory methods for helping science.

The solutions of the upstream engineering problems require the cooperation of all agencies, such as (1) the sciences of engineering, biology, chemistry, physics, agriculture, economics, sociology; (2) all governmental agencies—Federal, State and local; and (3) all intelligent and courageous industrial leaders and farmers.

The old American point of view was to build a comfortable home for our children. While we assumed or supposed this to be an easy and delightful task, privilege, and duty, we are coming to realize that our carelessness in the past has made it a serious and difficult matter.

I consider this a momentous gathering in that it has brought together an assembly of many able men representing many fields of interest and knowledge for a common inquiry and discussion for the first time. I hope that the lines of specialization will be sufficiently broken down to permit more such conferences. Therefore, let us get behind the present programs of conservation as representatives of the American people as a whole.

CHAPTER XII

Big waters and little waters

BY EDWARD M. MARKHAM, MAJOR GENERAL, CHIEF OF ENGINEERS
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I HAVE ENJOYED very much being present at this banquet held in connection with the Conference on Upstream Engineering, and particularly as it gives me an opportunity to talk to you on the subject of "Big Waters and Little Waters."

I remember an old quatrain which goes somewhat as follows:

> Big fleas have little fleas
> Upon their backs to bite 'em;
> And little fleas have littler fleas,
> And so, ad infinitum.

Big waters represent the accumulation of little waters, and the control of these little waters if multiplied sufficiently may contribute in time to alleviate the problems of control of the major stream which they feed. However, the economic solution of pressing problems at this time usually indicates that methods of control must be applied to the major streams themselves. I imagine that the application of the necessary medicine to eliminate only the little fleas would still leave poor dog Tray sitting in the sun trying to rid himself of the major fleas for a long time, and so our rich industrial valleys may suffer irreparable losses during the period of time required to control fully all tributary streams.

For example, the reservoir control necessary to reduce floods in the Delta of the Mississippi River would require the expenditure of well over a billion dollars and would take many years to complete. Even then it would be almost impossible to operate the tributary stream reservoir systems to prevent floods in the lower river, and a system of levee protection would still be essential. Timely protection within the limit of funds reasonably available can be provided in the Delta only by protective works located within the Delta to include channel enlargement, rectification, levee protection, and the provision of floodways through which excess floodwaters can escape. In smaller valleys the planned control of the tributaries may sometimes solve the flood-control problem on those tributaries, while at the same time giving the necessary protection to the main valley. In such cases headwater remedial measures are manifestly the economic solution.

Water has always been, and will always be, the major factor in the development of civilization, which can exist or expand only where an ample and reliable supply is available. The first engineering developments of record in the history of mankind were works designed to bring adequate water supply to centers of population, just as today the conservation of water is a major factor in the engineering activities and plans of the world at large. The problems of water vary widely throughout the world, and even in the different sections of our own country. The first use of water must be for domestic consumption and all other uses must be considered as secondary. Our courts have long recognized that the provisions of the National Constitution safeguarding the interests of interstate commerce, give the Federal Government control over the navigable waterways of the United States. Congress has indicated in various legislative acts a Federal interest in the control of power development, in the conservation of water

for reclamation purposes, in its impoundment to reduce flood losses and decrease soil erosion, and in combining these purposes when practicable in the waterway improvements undertaken by the Federal Government.

In recent years the pollution of our major streams by industrial waste and other means has rendered them unsafe for domestic use without extensive treatment and has destroyed their recreational value to the public at large. Legislation with a view to controlling such pollution has received the consideration of Congress and will undoubtedly become a consideration of even greater importance. These several uses of water indicate in themselves the complicated nature of the problem and the difficulty of finding between these interests (sometimes conflicting) the solution that is in the best interest of the Nation as a whole.

In the eastern part of the United States along the Atlantic coast, adequate rainfall renders storage for reclamation purposes unnecessary, and in general, storage for domestic water supply can be readily obtained within close proximity of centers of population. Pollution is a serious problem in view of the comparatively dense population centering in the stream valleys and the industrial development which has been built up to support this population. The concentration of population and industry provides an increasing demand for the development of hydroelectric power in this section. Recently severe losses from cataclysmic floods have aroused a strong public sentiment for the construction of detention reservoirs for the storage of flood waters. This storage may conflict with storage for hydroelectric purposes, and in such cases a determination of the more important of the two measures must be made. Congress has recognized these conflicting interests and has provided that flood-control reservoirs may be provided with pen stocks to permit the future development of hydroelectric energy if and when found feasible.

In the western portion of the United States where long dry spells are encountered, storage for agricultural purposes and for domestic use is imperative, and suitable storage sites must, in general, be utilized for these purposes. The periods of heavy rainfall are frequently seasonal, and flood storage can sometimes be utilized for the development of hydroelectric power and for conservation purposes. The power developed at such dams may largely be of a secondary nature and of value only where it can be delivered to a joint system. In the middle section of the United States storage for conservation purposes is particularly desirable, although in the regions subject to drought conditions, the availability quantitatively for such storage may be doubtful or the cost of the storage may be very high.

It is a beautiful picture to visualize the major streams of the United States controlled by reservoir systems combining storage for domestic water supply, irrigation, the development of hydroelectric power, and the impoundment of flood waters. Unfortunately the combination of these purposes in a single reservoir or in a unified system is normally unfeasible. There is an economic limit to the size of any selected reservoir to be determined by the water available for storage, foundation conditions, and the costs of the rights-of-way included in the reservoir area. Reservoir capacity needed for flood control must be fully available for that use at all times, which requires the emptying of the reservoirs as rapidly as possible after the subsidence of each flood, so that storage of this type may have little value for hydroelectric and conservation purposes. On the other hand, storage for hydroelectric purposes to be economically desirable must be available for fairly constant release throughout the year. A huge reservoir with a capacity of 21,000,000 acre-feet, such as is offered at Fort Peck, may satisfactorily combine several purposes. While the primary objective of this reservoir was to augment the low-water flow of the Missouri River during the dry season as an aid to navigation, the additional water released

during that period will increase the discharge of the river, thereby reducing its pollution and making available additional supply for other useful purposes. The reservoir will also store the flood waters of the upper river, materially reducing the flood damages now sustained for a long distance below the dam, and in combination with the stabilization program under way on the lower river will result in eliminating some of the huge annual erosion losses which have occurred in the past. The value of the incidental benefits which will eventually accrue from the Fort Peck Dam may even surpass its value for navigation.

While I have placed great emphasis on the large impoundments because of their special public interest and because they do represent the most effective means for combining several possible benefits in a proposed development, their construction is not necessarily the economic solution for flood-control purposes. Protection against major floods may be provided also by the construction of levees or flood walls, the enlargement of the discharge capacity of natural channels, and the provision of escape or diversion channels for flood waters in excess of the normal carrying capacity of the main channel. The most direct and surest method of protection is provided by the construction of levees or flood walls as they will provide definite protection against floods of a given discharge. Reservoirs in localities distant from areas damaged by floods are not so reliable in their effects, and their value for a given flood condition must depend in large part on the storage space available in the reservoir just prior to the flood. Frequently their operation must be governed by local conditions rather than by the conditions which will affect the system as a whole. As a result, levee protection for important areas can often be provided at a fractional cost of a lesser degree of protection by reservoir storage.

We have heard much in recent years of the increased flood heights now sustained. I doubt if this is borne out by the records. There is no doubt that the damages caused by floods have increased, as human activities intensify flood destruction. Homes and business houses are built by the river's edge to utilize the advantage of cheap water-borne transportation and assure ample water supply for household and industrial purposes. As a result, the highly developed area subject to floods is constantly increasing so that each flood exacts a heavier toll than the preceding flood. The development of these areas now represents too much of a capital investment to think of their abandonment, and protection must be provided when feasible from an engineering and economic standpoint. The War Department plans and executes its stream-improvement work and the Department of Agriculture pursues its soil- and water-conservation work without conflict. Up to the present time these beneficial activities have scarcely come in contact. When they do approach each other, these two Departments will cooperate in the cordial and friendly spirit that has always existed between them. The direct benefits to flood control which result from forestation and soil control over a considerable period of time, are unquestionably an asset in preserving and lengthening the life of the structures and improvements providing for immediate control of excessive flows in addition to their immediate benefits in land use. They may also, over a period of years, contribute to the reduction of the normal or annual flood. Nevertheless, it must be recognized that the major floods which have caused so much disorder and loss of life and property, have resulted at intervals of several years from abnormal conditions, such as occur with extraordinarily heavy rainfall during a period in which melting snow and ice are contributing heavily to stream discharges, and the ground is frozen except for the top few inches so that a very high degree of run-off is obtained. These cataclysmic floods can be controlled only by major remedial measures.

The War Department completed two reservoirs on the Winooski River with Civilian

Conservation Corps labor. During severe floods of this spring these reservoirs served practically to eliminate the damages which, under similar conditions of rainfall and run-off, had formerly been so severe in that valley. The reservoirs offered a combined storage of 32,800 acre-feet, which was almost entirely utilized for the impoundment of flood waters. This storage could not have been provided physically in small dams or reservoirs, even had the necessary funds been available for the construction of the large number of small dams required for the purpose. I think it essential that in planning for flood control we separate in our own minds the problems occasioned by the annual or of what may be called "normal" flood, from those of the major floods of rare or infrequent occurrence. The problems of the two are very different.

Congress in adopting general flood-control legislation has recognized the importance of stream improvements related to land use, and has authorized cooperative studies to be undertaken by the War Department and the Department of Agriculture. These studies should do much to develop the desirable form of remedial measures with all factors taken into consideration, and should permit a more definite evaluation of proposed improvements than can now be made.

Congress in this same legislation established for the first time in our history a national policy for the participation of the Federal Government in the execution of flood-control works where found economically justified or for the protection of human life and property. It wisely included therein provision for substantial contribution by the benefited interests, requiring those interests to furnish the necessary lands and rights-of-way and to assume responsibility for any damages arising from the execution of projects and for their maintenance and operation. The Government cannot be an insurer of its citizens against the hazards of the elements. We shall always have flood and drought, heat and cold, earthquake and wind, lightning and tidal wave, which are all too constant in their afflictions. The Government cannot undertake to reimburse its citizens for loss and damages incurred under such circumstances. It can be charged with the rebuilding of public works and the humanitarian duty of relieving its citizens from distress. If the Federal Government bears the cost of engineering structures for flood control justified by the national aspects of the problem and by its beneficial influence on the welfare of the people, then the States and local interests may well afford to contribute the other costs, as the States will receive the direct benefits from the increased taxes from the lands and property made more valuable by reason of its protection.

The policy of the Federal Government with respect to stream improvements for navigation has been built up over a period of a hundred years and is clarified and enunciated in a number of court decisions. It is, however, embarking on a flood-control program with a clearly enunciated Federal policy for the first time. The years to come may develop desirable changes in that policy, and further legislation and court decisions may, and undoubtedly will, play an important part in clearly defining the responsibilities of the Government and the several States. The legislation marks a forward step in the conservation program of the National Government, and the developments of the next few years, as its provisions are placed in effect, should be of interest to both engineer and economist. The scope and magnitude of the work make it an important part of any future development plan. It will call for the utmost cooperation between the agencies charged with its execution and the several States. I am indeed glad to have had this brief opportunity to outline my own views with respect to the uses of water, and to express my conviction that the necessary cooperative effort between the States and the Federal Government will be attained.

CHAPTER XIII

Control and use of little waters in France

BY M. ALBERT MAGNEIN, OFFICIAL DELEGATE
ADMINISTRATION OF WATERS AND FORESTS, PARIS, FRANCE.

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I BRING YOU the greetings and the compliments of our director, Mr. Chaplain, who has kindly appointed me as delegate to your conference to represent the French Administration of Waters and Forests.

I read with the greatest interest the remarkable study on Little Waters which was sent to me, and in which the problem of soil conservation and water utilization is most clearly discussed. What have we done in France concerning this double point of view? I shall tell you as briefly as possible.

Concerning soil conservation we, in France, have to struggle against dangerous waters, those of torrential rivers, and especially Alpine waters which were described in detail by Mr. Mougin, our inspector general, in his book entitled "The Restoration of the Alps", from which I shall borrow major data concerning torrents. Although the problem of regulating great torrents does not seem to be of prime importance in the United States, nevertheless some useful information can be obtained from studies made in the mountains on the action of water and the movement of soil. Keeping due proportion, one may observe that the same phenomena exist in less mountainous regions and that remedies may be effected by some of the processes used for small ravines.

The rise of torrents contributes to the floods of the most important rivers into which they flow but these torrents are especially dangerous in the mountains themselves, because of their violence, the abundance of debris which they carry along, and the terrific rapidity with which they are able to bring devastation.

In an active torrent, the eroding effects of the water are dangerous for different reasons. The steep, funnel-shaped catchment basins accumulate the water with unbelievable rapidity. The crumbling nature of the soil transforms the water of the torrents into mud flows. Because of their density and speed these mud flows transport enormous boulders. In addition, there is the problem of channel diversion caused by the accumulations of previous floods at the foot of the slopes.

When a storm, particularly a hailstorm, breaks over a drainage basin, mud flows may carry down boulders, start landslides of banks, and submerge agricultural lands, including, at times, houses built on the slopes.

For a long time it has been known that the phenomenon of torrents depends on the intensity of atmospheric precipitation and on the presence of steep slopes of soft soil. Man has no defense against these two factors. On the other hand, the protection against the mechanical shock of rain and hail and against the smoothing effect of avalanches and the rapidity of runoff (and, therefore, the suddenness, the duration, and the importance of floods) depends largely on the wooded state of the slopes. It is up to man to conserve or reestablish this wooded state, because only forests can succeed in the struggle against torrents.

The four principles formulated by Surell, and confirmed by observation of conditions, are as true today as they were in 1841. They are as follows:

1. The presence of a forest prevents the formation of torrents.

2. The destruction of a forest leaves the soil the prey of torrents.
3. The development of forests helps to suppress torrents.
4. The cutting down of forests revives the suppressed torrents.

A multitude of examples support these four principles.

Let us first examine the results of deforestation, taking as an example Savoy, for which we have precise data. From 1738 to 1912 the forests of Savoy lost 21 percent of their extent. What has been the effect on the drainage system of that region? In order to compare streams at different times, one must be sure that the river bed has not changed to a great extent and that the observations have been made correctly. These conditions exist for the Rivers Leysse, Arc, and Arve.

In the eighteenth century the River Leysse had 8 disastrous floods and in the following century, 38. The floods had, therefore, become 4.7 times more frequent. In 1738 the forest covered 13,500 acres, or 53.2 percent of the drainage basin. In 1910 the forest covered only 9,870 acres. It had lost 27 percent, or more than a quarter of its former extent.

The River Arc, 200 miles long, had very little protection of its banks, except for the lower part between Croix d'Aiguebelle and the confluence with the River Isere, i. e., in the valley of the River Isere, which for a length of approximately 7¼ miles is protected by two levees. One may believe that the interruptions of communication between the two towns of Chambery and Turin caused by floods were carefully noted by the bureaus of the Controller General and by prefects. Records are noted of 11 disastrous floods during the eighteenth century and 37 during the last. The increase is, therefore, in the ratio of 3.4 to 1. The basin of the River Arc included, in 1738, 101,500 acres of forest. Since then it has lost 29,800 acres or 29.4 percent. The rate of forestation decreased from 20.7 to 14.6 percent.

In spite of its regulation, the River Arve had 11 floods in the eighteenth and 44 in the nineteenth century.

Torrential erosion also increased in Savoy between the eighteenth and nineteenth centuries, the number of mud flows rising from 70 to 297, or by the ratio of 1 to 4.2. In Maurienne the increase during the same period was in a ratio of 1 to 5.2. Floods in the Savoy have notably increased since the eighteenth century. Dangerous floods have become three to four times more numerous while the rate of forestation has decreased from 28.6 to 23.2 percent. This is indeed the relation of cause and effect.

The beneficial results of reforestation on many torrents are enumerated in Mr. Mougin's book. I shall discuss only one of the most successful examples, that of the region of the Labouret, in the lower Alps where a magnificent forest was planted on land which had been previously devastated and ravaged by a dangerous torrent. Work was started on this torrent in 1864. Up to the present time 446 small dams and 171 brush checks have been constructed. Today this torrent is completely extinct and its bed now carries clear water. I need not recall to your attention the influence of forests on run-off. Just let me give you a few interesting figures concerning the control of waters through forests. The ratio between maximum and minimum stream stages is lower for rivers draining well-wooded areas. This ratio has the following values for various regions:

River Verdon at Greoux	0.36
River Arc at Termignon	1.156
River Isere at Grenoble	.21
River Durance at Sisteron	.53

The percentage of wooded land in each of the drainage basins is as follows:

	Percent
River Verdon	42
River Arc	16
River Isere	27
River Durance	31

To be absolutely comparable, the preceding figures should refer to identical basins. But even such as they are, the indication is valuable.

It may seem, therefore, from what I have just explained, that the only thing necessary to be done, is to increase the area of forests. Unfortunately, this can be done only in rare cases because of the instability of the soil resulting from the action of torrents. This instability has frequently been created by the eroding of soil in longitudinal and lateral directions, through the action of the torrent. A speed at the bottom of a small stream of 10 feet per second is sufficient to erode the hardest rocks, such as granite; 5 feet per second to wear down schist and conglomerate; and one-half foot per second to wear through soft clay. As man has no more influence upon the abundance of atmospheric water, storms, or melting snow than on the geological composition of the soil, he must try to reduce the velocity of the torrent.

One may arrive at this by means of small dams or backfills. The slope of these backfills, varying in accordance with the size of the transported material, is always much smaller than that of the river bed. This will diminish the velocity of the water because of the increase in the wetted surface and the resulting frictional action. Furthermore, the backfill forms a cone which extends into the banks and stabilizes them.

This general method of correction, of which I have only mentioned the principle without speaking of the application cannot always be applied. When one bank consists of rocks and the other of soft earth, the sliding of the latter may endanger the stability of the structure and remove its entire efficacy.

The solution in such cases consists in diverting the torrent away from the soft earth bank and making it pass through a surface channel or a subsurface conduit cut into the hard rock. The foot of the earth bank will thus be no longer attacked by the water and will regain its stability. It is in this way that the village of Montdenis was saved after having been menaced with destruction by the torrent of St. Julien in Savoy. The torrent was diverted from a sliding bank by means of a tunnel.

In smaller and less dangerous streams one may be satisfied with simpler structures in order to diminish and control the slopes. In those cases rubble stone dams, log dams and brush checks will be sufficient. For these dams brush is used that can put forth suckers which take root in the banks and stream bed, thus increasing the strength of the structure.

If the ravines are smaller or carry very little water, one can stop erosion by means of branches laid at the bottom of the ravines. The branches should be fastened at regular distances by cross bars, with the upper part of the branches pointing upstream. Fast growing trees will quickly form a protective vegetation. Finally, in ravines where the slope is too steep for the effective use of dams, one may pave the trench to allow the water to run off rapidly without causing erosion. Briefly, these are the principal corrective methods used in our mountains.

As soon as the soil is sufficiently stabilized, it is only necessary to protect it against the "bombardment" of rain and hail and to prevent runoff. It is important to cover the soil with vegetation as rapidly as possible. First of all, one can often use resinous woods which are particularly suited for submarginal soil, and which cover the ground well and enrich the soil with their leaves. Later on, other trees existing in the region and which are more delicate can be introduced. One may use various other types of vegetation; it all depends on the particular circumstances. If the surface of the soil has a tendency toward sheet erosion, it is covered as rapidly as possible with herbaceous plants.

I have already indicated to you the marvelous result obtained in the Labouret, in the lower Alps, after the correction of a torrent and reforestation. Another work of reforestation of several thousand acres has been accomplished with great success in Aigoual, south of the Cevennes Mountains.

Concerning the Alps, detailed results of the works undertaken to conserve the soil have been described by Mr. Mougin in his book.

For the entire French territory between 1861 and 1935 the French Administration of Waters and Forests has reforested approximately 1,190,000 acres at a cost of 317 million francs, of which 57 million francs have been spent for corrective works. The social importance of works of correction and reforestation executed in the Alps is considerable. It was not only necessary to protect roads cut from mud flows, but it was particularly important not to allow streams to carry away topsoil from a village or the smallest hamlet. These areas, cultivated with affection by the present inhabitants, help to keep these people in their home communities. If a flood carries away the soil, this inhabited center will definitely disappear. Later on, the forest which has saved these mountain people from exile and preserved the soil, will also give them work.

Water can cause erosion only if the soil is completely deprived of forests and herbaceous plants. It is, therefore, necessary to avoid everything that might destroy this protective cover. Heavy grazing, particularly in the high mountains, has a disastrous effect. The trampling by the animals leaves the soil easily a prey to erosion. This is the reason why the French Administration of Waters and Forests at the same time that it tries to stop erosion caused by torrents is anxious to maintain pastures in good condition by means of adequate regulation.

Works of correction of torrents and the regulation of pasturage cannot be done without injuring certain private interests. Although the works are executed in the public interest, it would be illusory to count on spontaneous and even less enthusiastic cooperation from all landowners. A number of laws permit the Forestry Administration to overcome resistance which might occur. The first was the law of July 28, 1860, on the reforestation of mountains; the second of June 8, 1864, on the replanting of grazing lands; and finally the law of April 4, 1882, which abrogated and replaced the two preceding laws. By virtue of the present legislation, the necessary works for the restoration of soil can be declared to be "affected with a public interest" which permits the application of eminent domain on that land where work must be done. The law of August 16, 1913, has well supplemented that of April 4, 1882, by permitting the declaration "affected with a public interest" to be applied not only for construction works against erosion but also for those aiming at the prevention of floods.

Water is not the only agent of erosion. One must also contend with wind, which, under certain conditions, can bring about the destruction of arable soil by covering it up with sand. This happened in the Landes before works of dune fixation were undertaken by the Forestry Service in 1862 and has been continued ever since. The technique of dune fixation is as follows: At a distance of between 100 to 150 feet from the reach of the highest waves, a seacoast dune is built by means of special fences. The work is continued until a dune 40 to 50 feet above sea level is created. In the shelter of this artificial dune various grasses are planted. A cover of branches is used to stop the wind from displacing the sand which eventually is stabilized naturally by the growing grass. The area covered by such works along the French coast is approximately 250,000 acres and extends about 720 miles along the coast line. The works built since 1864 have cost 13,000,000 francs and the annual maintenance costs are in the neighborhood of 200,000 francs.

It is not all to create forests, one must afterward protect them just as well as those which have been in existence before. French legislation has passed two laws for this purpose, that of 1859 on clearing of land and that of 1922 on forest protection. Restrictive measures concerning the clearing of land date far back. An ordinance of Francis I of January 1518, and one of Henry III in 1588, prohibited cutting on royal forests and on those of others subject to certain public rights. The ordinance of 1669 reiterated this prohibition. The law of September 29, 1791, passed during the revolution, gave landowners the full freedom of their woods, but cut-

tings became so heavy that the Government, by the law of April 29, 1803, was forced to restrict the right of destroying forests. During the years which followed, the text of these laws were modified and finally consolidated into the law of June 18, 1859, which is still in force. This law provides for the prohibition of clearing land whenever the forests are necessary to protect mountain soil and slopes; for the protection of the soil from the sea and the movement of sand; for the protection of land in border zones; and, for the benefit of the public health. As one may see, the scope of the law is wide and it is frequently possible to oppose the destruction of a forest by its owner.

Excessive exploitation may lead to the more or less complete disappearance of forests. The law of April 28, 1922, classifies as "protection forests" those which are considered necessary to protect mountain areas and mountain slopes from avalanches and erosion, and to prevent floods and the movement of sand. In forests, so classified, the owner is compelled to apply for an official cutting permit from the Administration of Waters and Forests. Without such a permit no cutting can be done except by special authorization.

Fire is another enemy which threatens forests and against which precautionary measures had to be taken. First of all, preventive measures were necessary, such as the creation of firebreaks, the organization of fire guards possessing a system of rapid communications, and the institution of fire-fighting corps in all localities adjoining the forests. The two most dangerous regions are in the Landes and along the Mediterranean coast where the pine trees and the underbrush are particularly vulnerable. During the summer season, fire watchers are on duty at vantage points and give an alarm as soon as they notice smoke. In the Provence, the system was brought to perfection by the construction of watchtowers equipped with radio transmitters. These stations can communicate at all times during the day and night with the radiomarine station in Marseilles, and the operator notifies the fire service immediately by telephone. A law of 1924 defines the obligations of forest owners with regard to fire fighting.

The majority of damages done to forests can be traced directly or indirectly to man. If man could only realize the importance of the part which forests play in the life of a country, the devastations would be fewer.

To convince the public and to educate them toward respect for the forest, if not toward love for them, the French Forestry Administration is sponsoring an active campaign in schools, emphasizing the formation of forestry clubs by the contribution of seeds, plants, and monetary gifts.

Two organizations are giving valuable cooperation to the Administration: First, the Touring Club of France, the powerful organization of French tourists, which has published for forest-educational purposes the "Manual of Trees" and the "Manual of Water"; and second, the Oak Society, the activity of which extends over the entire south of France. This society has sponsored forestry classes in teachers' colleges, and through publication of its magazine, contributes to a broader understanding of the beauties of French forests.

The utilization of water for power and irrigation is not controlled in France by the Administration of Waters and Forests. It is more interested in fish raising. Having read in "Little Waters" a passage concerning the region of Dombes, I shall give you some information as to the methods used in this particular region.

This region forms the southern part of the district of Bresse. It is a rolling plateau and the soil is formed of a glacial clay, hardly permeable. The upper part of the soil can be more or less penetrated by cultivating machines, but beyond 20 inches the soil becomes so compact that it is difficult to dig it with a spade. Because of the profile of this region and the impermeability of the soil, the Dombes is covered with ponds which for many years have been used for the raising of fish. Previously, the region of Dombes was

unhealthy because of these permanent ponds, but the situation has changed since corrective practices have been introduced. During the entire period that these lands are under water, the bottom of the pond becomes richer through deposited organic matter of animal and vegetable origin. When the pond is drained, this dung assures a fine crop of cereal plants, especially oats.

The system of fish raising and cereal farming together with the existence of a railroad for the rapid transportation of the product raised have brought to the Dombes a prosperity which is in direct contrast to its previous poverty. According to statistics, population density has increased and health conditions are very favorable.

The surface of the Dombes is covered with rolling hills. In the basins between these hills ponds have been made by building dams in order to retain floodwaters. A system of sluice gates provides for the drainage of the pond, and grills hold back the fish. On the bottom of the pond there is a system of small channels and trenches to facilitate the drainage of the impermeable soil. In the middle of the pond is constructed a large ditch which traverses the full length of the pond and ends at the sluice gate. The fishpond is established at the deepest spot. At the periphery of the pond girdling ditches are built. Finally, parallel to the main ditch are dug a series of other ditches which are connected with one another and with the central ditch through a series of small channels. Two adjoining channels are separated by a ridge. By this arrangement the water falling on the surface of the soil is drained and gathered in the main ditch; when the sluice gate is open the water escapes through an overflow channel.

The filling of the pond takes place usually in October. First, the soil is plowed in a direction perpendicular to the main ditch. The fishpond is cleaned at the same time. Then the sluice gate is closed. Rain water gathers in the basin and, if rains are plentiful, 99 days will be enough to fill the pond. The depth of the ponds, therefore, is in direct relation to the hygrometric state of the atmosphere. It does not exceed 5 feet in the central part; in the fishpond it reaches about 10 feet. But the depth of the water is subject to great fluctuations and long periods of droughts constitute a great danger.

Fauna and flora of the pond are extremely rich. Fish find abundant food. One puts in mainly carp, some pike, and some perch. The ponds generally remain under water for 2 years and are cultivated in the third year. The fish are taken out at the beginning of the winter in order that the first frost may destroy the aquatic plants which form good fertilizer for the cultivated crop. If not destroyed, these aquatic plants hamper cultivation. The present surface of the ponds in the Dombes is approximately 25,000 acres.

There are in France many other regions containing a considerable number of ponds but none of them exceed the great surface of those in the Dombes. Most of these ponds were created in the Middle Ages by religious communities and by feudal seigniors, on their large estates to provide food for the great number of fast days (140 out of 365) imposed by ecclesiastical laws. At the present moment one can estimate the productive extent of lakes and ponds in France at 325,000 acres.

While surface water is frequently used for power, irrigation, and fish raising, underground water is rarely utilized directly. One example exists in the Cran, a stony plain east of the River Arles and the Rhône. Most of the land was covered with lean pastures for cattle. The surface of this plain is separated by an impermeable layer of soil 30 feet thick from a heavy stream of clear water. The stream is supposed to be the old bed of the Durance which now joins the River Rhône much more to the north, at Avignon. This water is brought to the surface at certain points by drilling wells and installing pumping stations. After the land was cleared of stones and irrigated, fruit trees, grazing land, and vegetables replaced the poor grass of the former desert lands of the Cran.

CHAPTER XIV

Building toward a Permanent Agriculture

BY JACOB G. LIPMAN, DIRECTOR
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HISTORY repeats itself in soil wastage as it does in other fields of human concern. There is a certain sequence in land-use practices in many lands and places. This may be readily illustrated by references to the evolution of agriculture in different countries. In England, for instance, primitive farming of the twelfth century had something in common with eighteenth-century farming in the New England colonies. We may compare here statements made by Prothero and Eliot. According to the former: "Improvements in the art and science of English agriculture were in its infancy dependent on the exhaustion of virgin soils. So long as land was abundant, and the people few or migratory, no rotation of crops was needed. Fresh land could be ploughed each year. It was only when numbers had increased and settlements became permanent, that farmers were driven to devise methods of cultivation which restored or maintained the fertility of their holdings." [1] The same condition is described by Eliot. "When our forefathers settled here, they entered a land which probably never had been ploughed since the creation; the land being new they depended upon the natural fertility of the ground, which served their purpose very well, and when they had worn out one piece they cleared another, without any concern to amend their land." [2]

Thus in the story of human wanderings we observe the phenomena of land abundance, of soil depletion, and of migration. The same story is told in the ebb and flow of human tides, in the rise and fall of empires, in widespread famines and pestilences, in border raids and clashes of armies and the the time-worn shibboleths about a place in the sun and the right of might. Much of this might have been spared to mankind if there had been less soil erosion and leaching, less overgrazing and burning and more restoration of the elements that go into the making of plants and animals.

The concept of "worn soil" is not only old but common to many regions. The Bible transmits to us traditional information of "resting the land." A long time ago farmers came to the conclusion that soils could become tired and that the so-called process of resting the land involved either fallowing or the abandoning of fields to weeds. The so-called three field system so common in western Europe and North America in the eighteenth century was based on the conception of resting the land. The recognition that land may be damaged by erosion and leaching came to farmers in olden times and in many lands. Early writers on American agriculture make reference to damage by erosion. Such references may be found in the literature of the eighteenth century. Perhaps the most vivid and dramatic description of damage by erosion is found in the writings of Solon Robinson who traveled in the Southern States in 1845. While this is not the time or place for lengthy quotations, your speaker is tempted to cite at least one brief statement of Robinson's. He writes:

I cannot urge it too strongly upon Warren County farmers to become shepherds or orchardists if they wish

[1] *English Farming—Past and Present,* Cambridge, 1917.

[2] *Essays Upon Field Husbandry in New England, etc.* 1748–62, by Jared Eliot, Columbia Press, 1934.

to see their hillsides descend unimpaired in fertility to their children, instead of descending to the Gulf of Mexico and the gulf of destruction. * * * Cotton—cotton—cotton—till the land is cottoned to death, because cotton is the "great staple", which in the opinion of the cotton planter, only needs to be sustained, and that will sustain all the links of the great chain of commerce—forgetting that the support of that staple, into which it was driven pretty hard a few years ago, was nothing but a "quicksand bank", and the floods came and the staple drew out, and down went the chain, dragging prosperity and improvement with it. * * * And if the present system of clearing up new land and cultivating in cotton until it will no longer produce a crop, is persisted in for only one little short century, our posterity need not trouble themselves about "overproduction", for the whole South, Texas included, will be too poor to produce a supply.

There is no need at this time to quote from the recent writings by Bennett and others on the extent of erosion damage involving both gullying and sheet erosion. By way of contrast, we may note the land-use practices in some of the western European countries where a plant cover, be it of forest or grass, is used most effectively for protecting the land against erosion and, in considerable measure, against leaching. We may note likewise the age-old practices in the Far East as described, for instance, by King in his book entitled "The Farmers of Forty Centuries." In some sections of China and Japan soils have been conserved and made more fruitful by rational methods of soil management.

As we consider the several factors responsible for soil deterioration, we note readily the significance of gully and sheet erosion, wind erosion, the creeping of soil material to lower levels, the dissolving of a portion of the soil material and the carrying away of such dissolved material in the drainage systems, the removal of very substantial quantities of plant nutrients in crops and in animals, the loss of organic matter through rapid decomposition, the deterioration of soil structure, the accumulation of acidity, the concentration of soluble salts in the surface soil, and the development of plant and animal deficiencies reflected in physiological abnormalities. Your speaker must content himself with only the briefest mention of some of the major phenomena which concern soil deterioration in the United States. For something like two decades he has been engaged in the study of data relating to what might be called the inventory and balance sheet of plant nutrients in the United States. Bulletin 607 of the New Jersey Agricultural Experiment Station, which recently appeared in print, contains a general summary of some of the data which were developed in this study. Without imposing unduly on your patience, I wish to quote only a few of the figures which have to do with the removal of six of the plant nutrients from the soils of the United States. These nutrients include nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. The data which may concern the corresponding loss of other plant nutrients are not sufficiently complete to permit of a reasonably definite estimate. In general, it may be said that the losses of these six nutrients charged against harvested crops, grazing, erosion, and leaching, would represent, in round figures, something like 23 million tons of nitrogen, 4¼ million tons of phosphorus, 50 million tons of potassium, 68 million tons of calcium, 24½ million tons of magnesium, and 12 million tons of sulphur. There are compensatory factors. In the case of nitrogen and of the other nutrients, fertilizers, liming materials, animal manures and bedding, rainfall, irrigation waters, seeds, and fixation by microorganisms constitute additions to the inventory ranging from about a million and a half tons in the case of phosphorus to 16 million tons in the case of nitrogen.

If we consider the net losses, we find that each year our soils are becoming depleted annually to the extent of more than 6½ million tons of nitrogen, 2¾ million tons of phosphorus, 44 million tons of potassium, 55½ million tons of calcium, 20½ million tons of magnesium and 3 million tons of sulphur. This rate of soil deterioration represents a most serious impairment to our national capital. This impairment of our

national capital may be described in both qualitative and quantitative terms. As to qualitative terms, Dr. Orr notes in his "Minerals in Pastures", (pp. 138–139) that "The pathological conditions due to these deficiencies have received various names in different parts of the world, but the symptoms and lesions fall into definite groups according to the nature of the deficiency. Thus, "styfsiekte" in South Africa, "coastal disease" in Australia, the "creeps" in Texas, and "Waihi disease" in New Zealand, which are all due to deficiency of phosphorus, have essentially the same symptoms. In the same way osteoporosis due to lack of calcium, goitre due to lack of iodine, or anaemia due to lack of iron, present similar symptoms in whatever part of the world they occur."

Quantitatively speaking, we may describe our soil losses in terms of acreage or in terms of plant nutrients. Much has been said about the extent of damage that has been done by gully and sheet erosion. We need go no further than the attractive booklet entitled "Little Waters" recently published by the Soil Conservation Service, Resettlement Administration and Rural Electrification Administration. On page 2 of that booklet reference is made to estimates of erosion damage supplied by specialists in this field. We are told that "They find that 100 million once fertile acres of farm land—equal to Illinois, Ohio, Maryland, and North Carolina combined—have been essentially destroyed for profitable farming; that another 125 million acres are seriously impaired; and that another 100 million acres are threatened—all belonging to the best farm lands of the United States." Whether the area of land irreparably damaged by gullies is 30 or 50 million acres, we may readily agree that the damage has been and is great enough to constitute a threat to our future well-being as a Nation. If we attempt to estimate the damage in terms of replacement costs of plant nutrients, we find that, if the farmers of the United States attempt to purchase a sufficient tonnage of the six nutrients already referred to, to offset entirely the losses from their soils, they would have to expend, at retail prices, something like 7 or 8 billion dollars, an amount approximately equal to the entire farm value of our staple agricultural products.

Of course it is not necessary for us to consider the replacement of all of the plant nutrients removed from our land by erosion, leaching, cropping, grazing or in other ways. Indeed, there are compensations where sheet erosion occurs, and where it is slow enough to permit the maintenance of a minimum amount of organic matter, there need be no serious soil deterioration, for new mineral matter is brought nearer the surface and represents, to that extent, a replacement of what has been lost. Despite the fact just noted, the losses are serious enough to involve declining fertility and lower standards of living over many thousands of acres of land in the United States.

But we should not give ourselves up to discouragement when we study and observe conditions relating to soil deterioration in the United States. We know that levels of soil fertility may be raised as well as lowered. No more striking example can be cited than that of the yield levels in England during the thirteenth century. In that period, wheat yields had declined to something like seven bushels per acre. Today the average production of wheat in England, Scotland, and Wales is well over 30 bushels per acre. The latter part of the eighteenth century and the first half of the nineteenth century saw the development of so-called "high farming" in England. Production has been built up and is being maintained at a high level. No less striking is the lesson that we may draw from the agriculture of other European countries, particularly the Scandinavian countries, the Netherlands, Switzerland and portions of Germany and Czechoslovakia.

In thinking ahead toward an effective program of soil conservation, we must fix our thoughts on certain of the major factors which have to do with the maintenance of soil fertility and the

building of a more or less permanent agriculture. We recognize that land subject to erosion must be kept under a plant cover that is adequate and effective. In some areas forests represent the most effective plant cover; in others, a grass sod is the desirable type of plant cover. In general, our soil conservation program should reckon with forest, pasture and meadow management, with adjustments of livestock population to carrying capacity. We must provide for offsetting the constant drain of basic material from the humid soils of the country. In the same way, we must guard against the undue concentration of soluble salts in the surface portion of our semiarid and arid soils. We must recognize that countless generations of wild and domesticated animals have been concentrating phosphorus in their bones, muscles, and brain tissue. The result of this constant and continued concentration has been the development of phosphorus deficiencies over wide areas of the soils of the United States. However, the phosphate resources of our country are ample for restoring the loss, for increasing the supply of available phosphorus in our surface soils and for building toward higher production levels thanks to such restoration. The same may be said of supplies of potassium, calcium, and magnesium. We should be able to provide for replacing or for correcting deficiencies in respect to manganese, boron, zinc, iron, iodine and of other ingredients insofar as these may be a limiting factor in crop production. In a word then, we may assume that our present-day technical knowledge is sufficient for permitting us to correct physical, chemical, and biological deficiencies of soils for the sake of building toward higher production levels. We may anticipate that within a few decades our population will be stabilized at 150 to 160 millions. There is ample room in our country for a population of this size and with dietaries fully adequate for maintaining bodily efficiency, health, and vigor. Indeed, our soil resources can be made ample for a human population of 300 millions and of livestock populations in keeping with the needs of a population of 300 millions. Having studied and recognized the negative factors of land use; having become fully aware of the hazards and dangers to which we are exposed because of soil deterioration, let us set ourselves to correct and to build and to fashion environments that would stimulate and help us to climb toward higher levels of physical well-being and to the highest levels of culture, freedom, and righteousness.

CHAPTER XV

ON BEHALF OF A CONTINENT

BY MAURY MAVERICK, MEMBER OF CONGRESS
REPRESENTATIVE OF THE TWENTIETH DISTRICT, TEXAS

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MY SUBJECT is "On Behalf of a Continent" and in general I shall confine myself to various phases of conservation. But more than that, I shall try to show how you can help yourself and directly help your country.

You have been told time after time that in the old days life was much harder than it is now, and from a physical viewpoint this is correct. In the old days people had to work harder and thank God they had a glorious opportunity to work if they so desired; they did not have modern conveniences such as machines, electric lights, or automobiles, or any of the advantages that we have in modern society; but opportunity they had, and had plenty. If they were willing to work, they could get a good job, or own a farm or start a business.

Now, my fellow Americans, the surprising thing that I am going to tell you is that what you face is much harder than your mothers and fathers and grandfathers faced. You have a much harder time ahead of you than your parents had. My boy frequently replies to me when I try to tell him something: "Oh, yes; I know you had 14 cows to milk when you were a boy." Thank God I had the opportunity, he has no such opportunity. Our fathers and grandfathers were plainsmen, soldiers, pioneers, and citizens, who fought the Indians. They were brave and courageous men, men who built this great Nation and gave us an opportunity to have a place to live.

Nevertheless, from us is demanded the same type of courage and the same type of bravery in maintaining and improving our most precious heritage. While our forefathers banded together to meet the dangers of the forest and the Indian to establish their homes, we today must join together for a purpose requiring as much or more courage if we are to save the greatest gifts of Nature to us and make America a better place to live.

So today I am talking to you on the subject of conservation. Conservation of what? Well, what I propose to talk about is the conservation of natural resources, and when I say natural resources, it means our land, our water, our trees, our rivers, lakes, harbors, and everything which by nature exists for us in this country. Now why do we wish to conserve and preserve these resources? The reason is that we wish to conserve human resources. We—that is ourselves—have no particular sentimental interest in a river or a stream, although both may be beautiful. The truth is we must conserve these things in order that we may live like human beings.

So let us get right into the subject of conservation—the opposite of death and destruction, for conservation is peace and human relations, life, and building up. Let us be analytical awhile and go into the history of it; find out what is the matter in our country, what has caused it all, and last of all, what can be done about it. In connection with this, I want to point out some of the great opportunities existing for you and all young Americans.

Believe me, when we started settling this country, we did it with a bang. A great virgin continent lay before our forefathers—even before

our own living fathers. Increasing families, immigration, adventure, and economic pressure, all contributed to the rapid settlement of the country, from the Atlantic to the Pacific and from the Gulf to the Border. So we marched along, slashing and tearing as we went, laying waste behind us.

The truth is, forces which encouraged this rapid occupation of all our lands led the early settlers to believe that the land and other natural resources of this continent were limitless in extent; that this was a permanent country and that our soils, our forests, our streams, and our wildlife would last forever. But today we know this is not the case. With these mistaken notions uppermost in mind, probably no nation or people have been so wasteful and negligent of its resources in so short a period of time. We have acted like an untrained mustang, and it is time now to jerk this wild horse on its haunches and let it know it cannot eat unless it conserves its energies.

Other civilizations have disappeared for making similar mistakes. We can easily do the same—let us halt our wild course before it is too late.

If we do not check ourselves we can easily destroy this land of ours, such that we sink to a miserably low standard of living, with large deserts over the face of the continent. That is the tragedy of it, but the beauty of it is that we can stop it—you can do it—save it and build it up, and have a productive, fertile country in which you can live, your children can live, and your children's children can live.

We find that in the United States this misconception of a permanent country has built and is still building vast stretches of worn-out lands. As a result, thousands of farmers are now having to eke out an existence on land impoverished by soil erosion, and their standard of living is therefore sinking proportionally. The extent to which our farm lands have already been destroyed and how much more is in process of destruction is almost unbelievable. In the comparatively short time the country has been settled there has been ruined about 100 million acres of farm land, most of the productive topsoil has been removed from 125 million acres still in cultivation, and the process of wastage is getting a good start on another 100 million acres. At the present rate of erosion we are destroying about 200,000 acres of good farm land every year in our Nation and are seriously impoverishing a much greater area. This is not injury alone to farmers—it affects the whole Nation and every person in it.

But let us just consider the agricultural classes: What does this loss cost the farmers and ranchers? Reliable estimates place it to that group alone at $400,000,000 a year. But the total loss is much greater, when we consider the injury to highways and railroads and the losses resulting from the silting of reservoirs and streams which provide many thousands of people with water supply, electric power, and afford habitat for fish and wildlife.

The losses do not even stop here. As the topsoil is removed and the life-giving plant food is washed away, the farmer's crops become poorer and poorer until the land must be abandoned. Taxes no longer can be paid. Schools, churches, and other community activities suffer and insolvency of both the individual and community occurs. Farm populations must move elsewhere to engage in other pursuits or be transferred to relief rolls. The final chapter in the history of soil erosion is decadence and abandonment—a rotting civilization.

Let us be sure that the matter of soil erosion is not all; that the mismanagement of farming and ranch lands is not all. It further includes the broad problem of floods, and the control of our water resources; this includes the control of little waters, of big rivers, of great drainage areas covering many States and many wide portions of the Nation. Throwing up dams alone will not save us. In spite of millions of dollars spent on flood control, floods remain one of our serious problems, and occur every year in one or many

places in the country, inflicting human suffering and destroying property. On the other hand, too little water is also one of our most serious problems as is clearly shown by this summer's great drought which extends throughout most of our land. In some sections the water table has dropped to such an extent that water can no longer be pumped for household use and for watering livestock. The clogging of large and small reservoirs with silt and debris is impairing the efficiency of many of them for generating power, storing water for irrigation, or for furnishing water supply for cities. The dumping of industrial and domestic wastes into many of our rivers and lakes has seriously diminished or destroyed their usefulness for human enjoyment and a place for fish and aquatic life to live.

This heedless and cruel destruction of our soils and misuse of our waters is making for greater insecurity in the United States and if present rates continue, in another century, we may not be able to support our population anywhere near adequately.

I think I have told you, at least in outline form, what I started to tell you, and that is what is the matter. You can conclude that there is plenty the matter, and therefore plenty we can do; in fact that there is plenty we must do, if we are to save this country. How much more pleasant, how much more profitable, if we spend our time in the peaceful pursuit of conserving our soils, instead of the nervous pursuit of hunting imaginary Bolsheviks. It is into this picture that you fit, and that is the niche of the new engineer, the new technician, the new farmer—the man who works scientifically and pushes himself into the economic and political life of the Nation with his leadership and knowledge.

It shall not merely require farmers and forestry men, but engineers of all kinds. You must build dams and that will take civil engineers; you must build houses and that takes architectural engineers. You must have all kinds of men working on different processes of all kinds and that will take chemical engineers, and there will be others that will require mechanical and electrical engineers, because of the power that will be developed and sold to all the people of the United States.

It is my opinion that an intelligent plan of conservation is not only a matter of saving our soil and water in the usual way, but it includes the building of highways, bridges, power plants, and many other physical structures along with the proper training of citizens and farmers so that all of us can get the greatest benefits from our natural resources. This great new opportunity also includes finding ways to obtain the cooperation of municipalities, counties, and States. All this means a great field for young men in our various governmental units and it also means the employment of carpenters, builders, mechanics, and road workers. There is a field for investment, employment, and profit for business men, merchants and, for every single occupation on the face of the earth.

We have talked about what is the matter, and have also talked of what our new engineers and leaders can do. But let us discuss what has caused this and proceed on this adventure, and come to some conclusions.

Now it is obvious that the fundamental cause for this misuse, academically stated, has been a failure to conform our agricultural practices to ordinary natural conditions, and the violation of plain laws of cause and effect. If you cut all your trees down, overgraze grasslands, and cultivate your soil improperly, it is plain to an idiot that you lose the fertility of your land and finally all your topsoil; then, it becomes worthless to you and a menace to others.

It is true that this waste and misuse of our lands is partially the result of lack of knowledge of proper methods and partly from conditions beyond the control of individuals. Rather than adapting crops to the land and other natural conditions of rainfall and climate we have attempted too often to fit the land to the crops. Under natural conditions before settlement, the United States was covered with a luxuriant

growth of trees and grasses, each growing under conditions most suitable for its existence. This mantle of vegetation held the soil in place, maintained a rich humus, and utilized the rainfall to the fullest extent. Upon settlement, it was necessary to clear much of the forest land in order to raise crops and obtain lumber. As the population increased and the westward migration progressed the natural grasslands were turned under. Exposing the topsoil to torrential rains established conditions far different from those previously existing.

Without a vegetative cover to hold the soil in place and to retard the run-off of falling rains, erosion began its destructive work. In cutting the forests little attention was given to the young growth. Consequently young trees were destroyed by careless cutting methods or the fires that almost inevitably followed. Again the topsoil was laid bare to be carried away by dashing rains.

On the Great Plains the turning under of the native sod has permitted the topsoil to be blown away, some of it reaching as far as the Atlantic Ocean. The duststorms during 1934 and this year are hideous reminders of what has taken place. In addition to the removal of forests and the plowing under of grasslands, erosion has also been caused by overgrazing of range lands. The placing of more cattle or sheep on the range than it can adequately care for has caused the destruction of much of the grass cover with a resultant increase in erosion by both wind and water.

The time it takes to strip off the highly productive topsoil down to the stiff clay with low absorption capacity varies from a single year to many years, depending on local conditions and farming practices. In the past it has been more or less customary for farmers to brag over the fact that they have "used up" two, three or four farms. We now know that we have committed criminal waste—but could, if we wish, save our soil.

Experiments show us that the greatest losses of soil and water are from fallow soils. Next greatest are from clean-tilled crops like corn and tobacco. We also know that losses are negligible from fields covered continuously with grass or other dense crops.

Some reference should be made to other factors that have contributed to the increase in erosion in this country, factors which have accelerated the undermining of our most valuable resources. Included is the increase of tenancy and absentee owners. The deadly necessity of the transient tenant is money to stave off starvation, and while fighting for it, he cannot concern himself with soil and water conservation. Largely responsible for this lack of interest on the part of the tenant in maintaining soil fertility is the development of the short-term contract and the share lease.

The worst drought of a hundred years in the Great Plains area has called attention to another factor which has had an adverse influence on soil conservation. The old Homestead Act, designed for establishment of family-sized farms in the more humid regions of the country, has limited the acreage of farms in the semihumid areas to such an extent that farm income is not enough to maintain a family. What has happened is well known; the people have been forced to adopt many practices not suitable to the area with the result that much of the land has deteriorated and both the individual farmers and the Nation have lost heavily in the process.

In many sections of the country, much marsh land unsuitable for cultivation has been drained. These areas, originally the natural areas for wild fowl, were productive for two or three crops and then had to be abandoned; and now they are almost worthless for any purpose. In other areas ponds and lakes have been drained and streams have been dredged and straightened to such an extent that we have lost many of the beneficial uses of such waters, as for recreation, fishing, and stock watering. Instead of there being water almost every month of the year, many streams now have water in them a few months and are dry for the balance of the time.

This matter of stream flow brings up an important relationship between soil and water resources in headwater areas, and the water in the larger streams and rivers. The losses of soil and water from farm lands have a very direct effect on our streams and larger rivers and on the benefits which we obtain from them. The principal source of the waters in our streams and rivers is from the countless billions of raindrops which fall, in the first instance, on our agricultural lands and, by one course or another, finally reach the channels of the streams.

The destruction of the forests, grasses, and other vegetative cover permits these raindrops to reach the streams very rapidly by flowing over the surface of the bare soils. And as they rush on their way to the streams they carry with them the fine particles making up the rich topsoil. As this erosion process continues, eventually all the topsoil is lost, gullies form, and the rate of run-off is increased. The soil washed from the fields into the streams is no longer of use to the farmers and impairs the reservoirs and dams with silt.

Of comparable importance is the influence of this run-off on the flood problem of the larger rivers. All in all, floods are nothing more than an infinitely large number of raindrops, concentrated quickly into a single channel. This concentration process is greatly speeded up when erosion begins on the land. As it becomes worse the run-off becomes greater and this increases the volume and velocity of water which contributes to irregular stream flow and floods. It can be seen, therefore, that control of soil erosion is not only vital to the people in the upstream areas, but also to those living in the downstream areas of the larger rivers.

Before I shall proceed to the physical discussion of what can be done about it, let us consider what you new engineers must do about the causes that I have just mentioned. It is that you and all other good citizens must study these causes from the legal, constitutional, and economic viewpoint and set about removing them. For instance, let us say that much of our erosion is caused by land tenancy and share cropping. Let us physically restore the damage, but let us attempt to do away with the land tenancy and share cropping. I make this point in order to bring out that we are engineers who not only can draw a line or build a bridge, but men who assume the duties of citizenship and leadership. And moreover, since we are engineers who want to have jobs, and inasmuch as no one is going to rope us and tie us to a job, nor hand them to us on silver platters, we must create them ourselves. We must take an active interest in the laws and actions and cooperative efforts that will lead to these governmental solutions.

What can be done about it from the physical viewpoint if we are to maintain a permanent country with a permanently productive land? This calls for upstream engineering. We must, of course, have a continuing program of not only erosion control, but of real conservation and land build-up.

That this is of the utmost importance is shown by the fact that more than 75 percent of our farm and grazing lands are subject to the devastating effects of soil erosion. If we are to prevent the partial or complete abandonment of many sections of our country in future years, the task of protecting the land from increasing impairment and destruction must be continued from now on. In addition to the critical importance of protecting our soils from erosion, control measures in headwater areas are also needed to reduce the silting of reservoirs, to aid in controlling floods, and to obtain many beneficial uses of water that are not now available. To obtain maximum conservation and utilization of soil and water resources, our practices on both farms and streams must follow a coordinated program of proper land and water use.

Perhaps the first and most important step in preventing soil erosion on agricultural lands is to determine the crops most suitable to the land and other natural conditions. In general, the highly erosive areas should be retired from cultivation and planted with thick soil-holding crops,

such as trees, grass, and shrubs. Cultivated crops should be confined to the more level lands unless particular local conditions permit them on slopes. Even the more level lands should not be too intensively devoted to the growing of a single crop, especially clean tilled crops like corn, cotton, or tobacco. By alternating these crops with the growing of legumes in regular rotations, the soil can be conserved and fertility better maintained.

On the sloping lands, suitable for cultivation, the conservation of soil and water may be obtained by several methods, the application of each being dependent on local conditions. I will refer to them only briefly because the Soil Conservation Service can give you a full description of these methods. The practice most commonly employed is contour plowing. Contour plowing simply means plowing at right angles to the slope rather than up and down the slope. The ridges formed by the furrows retard the run-off and allow more of the rain to soak into the soil. Another practice is strip cropping. With strip cropping, clean-tilled crops are grown between parallel bands of dense soil-holding crops planted across the slopes on the contour. These latter crops catch rain water flowing down the slopes, spread it out and cause the suspended soil to be deposited and much of the water to be absorbed by the ground, thus protecting the crops growing on the plowed strips below. Still another practice is the construction of terraces to intercept water flowing downhill. Dependent on conditions, some terraces are designed to hold this water while others carry it off to the side of the field where it can do no damage. These methods are often used in combination to obtain the maximum conservation of soil and water on cultivated fields.

In those places where erosion has already made considerable progress and gullies have started, it is important that these be treated immediately. This treatment is generally done by the construction of small check dams or by planting grass or trees. The purpose of such treatment is to slow down the run-off water and to catch and hold whatever soil the water is carrying.

In addition to carrying out the practices which have been briefly referred to, many farmers may profitably construct small ponds or reservoirs on their farms by placing dams on small streams or utilizing natural depressions where rain collects. Many beneficial uses are obtainable from such ponds, such as for watering stock, for fish and fowl, and, where pumping facilities are available, for supplementary irrigation. During extremely dry years, such as we are now experiencing, and even for more normal years, a supply of water for irrigating gardens and orchards may often mean the difference between a crop failure and a good yield.

In a coordinated plan of conserving our land and water resources many small communities may have the opportunity of realizing direct community benefits from the streams and small rivers in upstream areas. Where conditions are favorable dams may be constructed on these streams for many desirable uses. Perhaps one of the most important would be the development of recreational facilities. In other places, conditions may warrant the installation of a small hydroelectric plant. In other places perhaps the construction of dams and other slowing-up devices would offer control of local flood problems. Other problems in the conservation of resources may necessitate community action, especially where cooperative activities are needed to carry through an undertaking.

In carrying out such a coordinated program as has been indicated for the conservation and utilization of soil and water resources in our upstream areas, certain fundamental objectives should be sought. In the first place, every effort should be made to prevent erosion by slowing down the water so it cannot wash away the top-soil. In the second place, every effort should be made to promote the absorption capacity of the soil so that more water will soak into the underground storage. In the third place, effort should be made to realize all beneficial uses of water by

constructing ponds and reservoirs and by controlling small streams.

The execution of such a conservation program in the innumerable thousands of up-stream areas of our country would not only reduce the menace of soil erosion and produce many new immediate benefits but it would also contribute to the control of floods on the larger tributaries, and in some degree even on the main rivers. By promoting the absorption capacity of the soil through vegetative cover and proper farming methods, much of the water that now runs off quickly to the streams will be retained on the land where it falls. As a result, this water may not reach the larger rivers all at once, and some of it may never reach them.

Now we have discussed this problem practically from the viewpoint of what is the matter, the cause, and what we can do. However, as I have tried to show, the engineer-citizen must not only know this from an engineering viewpoint but from the view of the law and the Constitution, coupled with practical achievement.

In this program are involved the expanding functions of government. My opinion, based on some study, is that a real plan of conservation would involve the employment of 3,000,000 citizens of all types. Eventually this might mean many more, but at least the program will need millions of men for the professions—technicians, lawyers, doctors, public officials—and all the trades.

In this great program is one political concept which must form the basis of all your work. Engineer that you are, you must nevertheless know, understand, and, I hope, believe in this; that is the truth of democracy, and of the fundamental civil and religious liberties of the people.

What do I mean by this? Well, read the first and fourth amendments to our Constitution. There, as you know, we are guaranteed freedom of speech, press, and religion, and are guaranteed the right of assembly, and the freedom from unreasonable searches and seizures.

There is a tendency all over the world to destroy these ordinary democratic liberties. Why is this? The reason is that there are disturbed economic conditions; people are hungry. Inasmuch as the leaders lose patience as to how we can accomplish settled conditions, they then decide to use force. They put young men in uniforms and have them marching about like automatons. If anyone gets out of line they simply shoot him.

We must always demand that in this country the democratic processes be maintained because patience and hard work are the only measures that will bring us out of this depression. We are not out of the depression yet, and we cannot get out of it by repeating slogans, by using sharp words, or by having foolish visionary ideas like printing a lot of money in a Townsend plan; the only way we can do it is to coordinate and organize ourselves and then work our way out of it. The only problem we have is to find out how we get to work, but certainly we cannot ever find out unless we have full freedom to find out, to study, to think, and to carry on research.

Following this idea of maintaining our democratic processes, I think a study of the facts we have just recited in reference to our waste can be agreed upon by everyone. For it is factual that we have destroyed many million acres of land; it is factual that floods do more damage than ever before; it is factual that we have more duststorms than we ever had before. Everyone who has eyes and ears know that this is true; it is mathematically accurate. Therefore, if we are reasonable human beings, we must all agree that we must save our own country.

Now, using the freedom of your minds as citizens, let us go just as far as it takes us. And when we do this let us go into the adventurous fields of knowledge which lead us we know not where. It may lead us into ideals which are entirely different from any we had before, as it has happened time after time in history. We must always have in our minds the necessity for study and truth, and progress shall always stand

before us as a shining light. Let us think, for instance, of one single great project which comes under the policy of conservation and utilization of our resources—the Tennessee Valley Authority. The Tennessee Valley Authority covers seven States, which include the drainage area of the Tennessee River and its tributaries. As a pure case of flood control and necessity, these dams had to be built and more must be built for the same reason. Originally the great Muscle Shoals project and dam were built for the purpose of producing nitrates for the World War. Other dams have been built in connection with this, and the whole system is done not only for national defense but as a defense against the elements.

Now listen closely because I am getting into the matter of your Government and my Government, our Government, the Government of the people of the United States doing something for itself, which is called by the name of public ownership.

This water in the Tennessee Valley dams backs up. Finally it begins to pour over the top of a dam. Who built the dams? Answer—the taxpayers. The water drops over. Should we let that water be wasted? Should we let that water go on down the stream without using it if we can? No, certainly. So the Government of the United States began to produce power, electric power for the benefit of the people and they found that they could produce it for about half as much as private corporations. Immediately there was a great struggle; there was a great deal of propaganda about it; and it was insisted that the Government should get out of the power business and let this water go to waste, millions upon millions of watts and kilowatts of power as it went over the dam. I maintain that this should be styled as silly and that the Government should make a way to pay the taxpayers back for the money that is expended in the building of such dams.

Now why do I say this? In the first place it is just ordinary horse sense, and in the second place if we are to have conservation we want the conservation to pay for itself.

In and around the Tennessee Valley it is found that millions of acres of land have been destroyed because the land has been improperly farmed. Now a farmer is given aid so as to farm properly the land, to follow properly the plan of soil conservation. As a result the whole economy and the whole life of those people have been changed for the better. These six or seven Southern States will absolutely be brought up out of the mire and will be permitted to live with a decent standard of living.

This is a great engineering accomplishment, and it must be remembered that all of this is done under a democratic Government, by a free people for themselves, with free discussion and the severest criticism. In all this have figured some of the greatest engineers in the whole Nation. This cooperative effort could not have been accomplished except under the Federal Government. It had to be done, and the only way to do it was used.

Still discussing this as an example, we nevertheless encounter dozens of prejudices in this project. We are told this hurts the coal business in Pennsylvania. This is nonsense, for if you build up prosperity in one part of the Nation, you build it up in other parts. You will be told that the T. V. A. and similar enterprises hurt private initiative. That also is nonsense. It is quite the opposite: the cheap production of power, the increased individual earning capacity, the plan of conservation, the agricultural lands of the whole district, have improved the possibility of individual achievement and private initiative.

The T. V. A. is only used as an example, for cooperative effort is encouraged by many of our agencies of government, such as the Rural Electrification Administration, the Soil Conservation Service, the Bureau of Reclamation, the Department of Agriculture, the Department of Interior, and others.

Cooperation is the basis of all civilized govern-

ment; you hear a lot of loose talk about cooperation destroying personal initiative.

It is important that we understand this point: That individual rights of the citizen and individual opportunities of an individual for initiative can only be maintained by the cooperative enterprise, and the cooperative organization of the whole. Now suppose we had no government at all. Then, of course, the man who had the biggest army, such as exists in certain portions of China, would be the war lord, and the one most unscrupulous, the most cruel. He would be the one who by virtue of private initiative would have the most money, the most property, and the most wives. But we Americans believe democratic government requires cooperative effort to insure the rights of the individual.

Let all of you listen to what I say, for there is a place for all of you if you have the will, the ability to organize, and the sense to use your heads. Yes, though your struggle will be greater than your fathers', the romance of it can be greater. Where your fathers fought cold and heat, you can chain it, make power of it, and lighten the toil of humanity. Where your fathers fought blind elements, you can follow science, shining brightly like a star. Where others struggled for sustenance, you can through cooperation provide the better things of life. Where others ignorant of great changes, have made clumsy mistakes, you can with your knowledge point the way to freedom and life. In all this you can be a real soldier of peace, with eyes open and looking only at truth for a guide. If we are to save this grand continent of ours, if we are to have a permanent country, if we are to have more and better things, we must work and cooperate with each other on behalf of a continent.

CHAPTER XVI

THE HUMAN VALUE IN UPSTREAM ENGINEERING

BY CHARLES HARRIS WHITAKER, VIENNA, VA.

IN SPEAKING to the subject of the human value in upstream engineering, I hope you will indulge me to the extent of letting me approach the problem by the land route rather than by that of water. There is a striking parallel between water floods and land erosion and human floods and landlessness, and the parallel applies both in their cause and in their effect.

When I was a youngster and was beginning to watch with interest the acts and antics of my elders, there came a group of workmen to build a house across the street from my father's house. This was my introduction to the inductive method of which Dr. Millikan spoke in his brief tribute to the way by which a conscientious architect approaches his problem. As the days went by, and the house across the street began to take form, I became well acquainted with a pair of workmen who were to have more influence on my life than all else. What they taught me was deeper and more useful than all that any school or college could give.

I learned from them the idea of doing things rightly. For them there was no other way of working. It was a long time before I began to understand all their rites and their ritual, their squintings, their feelings of each stick of wood as they took it up. They would, at arm's length, hold it to their eye, and their eye would seem to come to rest for a moment as they looked down the edge of the stick. After a second or two it would either be laid aside or else it would be put on a pair of trestles, or horses as they called them, and then would begin the series of operations that left me spellbound day after day as the work went on.

As I have said, it was a long time before I knew the reason for these rigid squintings. It was not until I began to play with tools myself that I found out the need for straightness in timbers. Unless they were straight the whole work, as it went on, became a process of constantly changing measurements. Straightness, like rightness, was a cardinal principle in the making of a house. It was this experience, as well as the sheer delight that came from playing with tools, the choice of the right one for each particular operation, the leisured sureness with which each movement was made, that determined me, once and for all, to become a carpenter. This, I am happy to say, I was able to do, and, eventually, to build for myself several houses with my own hands.

But another incident, later on in school, led me also to wish to become an architect. That I also did, and while I formed the habit of thinking of buildings as buildings and never got well used to the high-sounding word "architecture", there came a time when the word suddenly presented itself to me with a rude challenge. "What", said the word, "do I mean?"

At that time I had become the editor of the Journal of the American Institute of Architects and, almost before I knew it, I discovered that the word "architecture" had more meanings than one could shake a stick at. There were men who said we can't have any real architecture unless the buildings had columns. There were other men, equally or even more intelligent, who declared that columns were ridiculous.

On no question of what was, or wasn't architecture, was there any agreement. Some adored the Gothic style, while others, equally eminent, cried out that it was only a romantic imitation of a method of building that was now dead. Small wonder that I then discovered how confusing and misleading was the high-sounding word "architecture", and the fog surrounding its use was at that time about to be made even denser by a new building method that turned all the old ones topsy-turvy. The new steel-skeleton type of construction was getting well into its stride. For centuries there had been no way to raise a building except with masonry load-bearing walls. The practical height to which buildings could be built in towns and cities was about six stories. To go higher than that meant that the walls would have to be thickened. Thus, there was little or no gain in space by adding upper stories. What was gained at the top was lost in the thicker walls needed at the bottom. The new steel skeleton thus overthrew the building traditions of 8,000 years. The steel structure carried the weight of all floors. The walls of the building needed to be no thicker at the bottom than at the top. One could gain all the space one wanted, merely by building higher.

It followed, quite naturally, that landowners saw a chance to collect more rent from a good piece of land. The art of rent collecting is first to make the people want land, then to charge them for using it. There was scarcely a town or city in America that did not become skyscraper conscious.

Just about the time when this new era of bigness was sweeping all before it, with no thought whatever of the human consequences, I had an experience that suddenly and vividly awakened me to the fact that it was not by the great big things that men made a civilization, but by careful attention to the little ones; just as those at this conference are now turning their attention not to enormous dams on huge rivers, but to little dams on little rivers.

Crossing on the ferry from Hoboken to Twenty-third Street, New York, one afternoon, I found myself standing on the upper deck near two women and a little girl. They were so close that I could hear their talk quite plainly. One woman evidently lived in New York, for she was pointing out the sights to her whom I took to be a sister. One by one the big and high buildings were named. At last we came abreast of the then highest one—the Metropolitan tower. "That's the tallest building in the world", said the woman from New York, with a modest note of pride. At that the comment ceased. The superlatives were exhausted. The little girl, however, after a moment of silence, turned to her mother and said: "Mamma, where's the littlest building in the world?"

Now it has always been true that cities have drawn people away from the country as fast as the conditions of life on the land made life economically too difficult and socially too desolate. This is a part of the human erosion that parallels the land erosion of deforestation and gullying. The new skyscrapers, however, sucked people away from the land precisely as though a human overflow were taking place. A flood of human beings literally began to descend upon the cities. The process of human congestion is now quite as familiar as that of the land and water problems that gave rise to this conference. Thus I need hardly do more than allude to it. The process of slum growth, as the most menacing aspect of human congestion, is likewise quite as familiar. Just as in ancient days there arose a thousand hovels for each temple or palace, so there arose a thousand slums for each skyscraper. There were momentarily pangs and pains, but the process went merrily on up to the year 1929. Then it was that the disaster of the human flood became apparent.

The process of congesting human beings tighter and tighter on land had built up an inflation of land prices that ran well into the billions. These prices were assigned to land and property because of the underlying human congestion.

When the stock market broke in 1929 all prices melted like snow before the sun. The prices which had been assigned to property, based upon human congestion, also went tumbling. The magnitude of the flood as a price disaster was beyond realization. The inflated prices, erroneously called values, stood as security for life insurance, investments, as trust funds, and as pledges for uncountable loans. The impending foreclosures would have wrecked and ruined every financial institution in the United States. There was barely time, to use an engineering simile, to throw up a dam. The Government had to come to the rescue with an improvised levee. Billions of dollars had to be poured into financial channels in order to prevent the chaos that would result from the melting away of the artificial prices that had been assigned to urban lands and properties.

This, then, is the parallel that I would draw between river floods and human floods. In effect each produced its disaster, its misery, and its suffering. When we look fearlessly at the land and building history of the United States, it is certainly to be dismayed. The members of this conference know what has happened to the land. Those who have studied the buildings, in regard to what is called "housing", will tell you that one-half of our population are now living in slums, or on the verge of them. It is not a very good record. But housing is just as much a land problem as is upstream engineering. If land is not for bettering the conditions of life, then what is it for?

In order to find out, if possible, why the building of America was becoming such a chaotic patchwork of skyscrapers and of slums, the American Institute of Architects, 20 years ago, appointed a committee to study primarily the relation of land to buildings. For 20 years the committee examined and weighed the evidence before it. At the end of that period, the committee wrote its final report, a part of which I would like to quote.

Were the face of the land swept clear of all of man's works, it is more than doubtful if we now would be equipped to set a rational control of land and it uses. When such an opportunity, on a relatively small scale, was offered in San Francisco, following the earthquake and fire of 1906, that community failed to adopt and execute the comprehensive and elaborate plan which had been prepared for a coordinated and functional layout for the city. The reason for that failure, that lost opportunity, was that the antiquated pattern of the city had been nailed tight by the existence and fixation of the vested interests of private ownership of land. In the struggle between the public good and private ownership of the land, the public interest lost out.

Assuming that we were to start afresh, and that we possess today the wisdom and power to create a scheme of land use that would fit the needs of our time, would this be the solution of our problem? Unless there were decided modifications in the private rights of ownership of property, anything we might now do, however good, would merely impose a 1935 pattern on our communities, which in a few years would again become a serious problem. The inevitable and ultimate goal would be achieved only when those attitudes, which we now associate with the term "ownership" (and which stand in the way of the exercise of complete drastic and flexible control by the public of private-land use) had been ceded to the public. At that moment, when the last of the vested interest of private ownership of land had been given up and public control had become complete, it would merely be a matter of academic opinion whether or not "ownership" of land by private individuals still existed. The main objective, however, would have been attained—we could plan, we could control, we could preserve, or change. Meantime within that range of freedom of action still permissible under the plan and control, private individuals might still be "owners" of the structures erected on the land, their ownership being thus conditioned by and limited by the basic public control of land use. * * *

The committee is not yet prepared to express and justify an opinion that *complete public control* of the use of land would be inadequate. Neither is the committee ready to assert that there must be a *complete public ownership* of all land as a sine qua non for the exercise of *complete public control* of land use, but, if future experience, added to that phase, shows no advance toward the essential and *complete public control* of land use, then this committee would face that issue squarely and would recommend both *complete public ownership* and *complete public control;* the former as an essential condition in order to achieve the latter. [The italics are those of the committee.]

It was Alfred Russell Wallace, one of the great-

est of scientists, who pointed out in his little book on land nationalization that man was a land animal and that without land he could not live. This is a fact which the committee recognizes, by plain implication, in its report.

That report, I also take it, might be considered an example of the inductive method applied not to the planning and designing of a single building, but the planning and designing of a civilization. The conclusions are those of a body of architects—of dreamers of dreams, if you like—bent upon discovering why they could not apply their skill and knowledge in directing the decent growth of American communities. If we consider their conclusions in relation to the state of the whole world, in which we now find ourselves, where the problems of saving our own land, in the United States, have grown to the magnitude that gives this conference such a national meaning, and yet where, in our world of today plans for land conquests are costing all nations incredible sums, to what other conclusion can we come than that the right use of land is the basic problem before all mankind?

Appendices

APPENDIX 1

THE PRESIDENT'S LETTER OF INSTRUCTIONS

THE WHITE HOUSE,
Washington, June 16, 1936.

Hon. HENRY A. WALLACE,
Secretary of Agriculture, Washington, D. C.

MY DEAR SECRETARY WALLACE: Upstream engineering will have a major part in efforts to save the land and control floods, and for that reason it offers a broad field of opportunity for the engineering profession. I am therefore in hearty accord with your suggestion that there be held an open conference on the subject in early fall. The date might well be in proximity to that of the Third World Power Conference in September, in the hope that some of the distinguished foreign engineers attending the latter may be interested also in contributing to the proposed conference.

There are indications that a substantial body of technical information on the control of little waters is now available in the scattered records of American experience—Federal, State and professional. The urgent problem is to bring these data together in a coordinate body of engineering knowledge so that public officials and engineers may have a more definite picture of the upstream engineering as an important field of public and professional activity.

There is a wealth of experience and data as to downstream engineering and works required for navigation, power development, and flood control—levees, large dams, great reservoirs and channel improvements on major streams. But necessary as these are for the safeguarding of those who live in areas subject to destructive floods and of property located therein, it must be remembered that downstream waters originate largely in upstream areas. The objects of upstream engineering are through forestry and land management to keep water out of our streams, to control its action once in the stream and generally to retard the journey of the raindrop to the sea. Thus the crests of downstream floods are lowered.

In accordance with your further suggestion I am appointing as a committee to organize and promote such a conference or institute: Hugh H. Bennett, Chief of the Soil Conservation Service, Department of Agriculture; Morris L. Cooke, Administrator of Rural Electrification Administration; and F. A. Silcox, Chief of the Forest Service, Department of Agriculture.

Very sincerely yours,

FRANKLIN D. ROOSEVELT.

APPENDIX 2

THE COMMITTEE'S LETTER OF SUBMITTAL

UPSTREAM ENGINEERING CONFERENCE,
Washington, D. C., April 30, 1937.

THE PRESIDENT,
The White House,
Washington, D. C.

DEAR MR. PRESIDENT:

We have the honor to submit in the form of a volume entitled "Headwaters Control and Use", the report of the Upstream Engineering Conference held in Washington, D. C., September 22 and 23, 1936, in accordance with instructions in your letter of June 16, 1936, appointing us as a committee to organize and conduct such a conference.

As stated in your letter, "Upstream engineering will have a major part in efforts to save the land and control floods, and for that reason it offers a broad field of opportunity for the engineering profession. There are indications that a substantial body of technical information on the control of little waters is now available in the scattered records of American experience. The urgent problem is to bring these data together in a coordinate body of engineering knowledge."

This report, we believe, is noteworthy in that it assembles under one cover for the first time a fairly complete treatment of the subject in the light of present knowledge: the basic scientific concepts and data; the specific objectives and techniques of application of these concepts in the control of waters in the various forms they take before becoming large streams; and general considerations of the social values to be realized through a comprehensive program of control and use of headwaters.

General interest in the subject was manifest in cordial cooperation from many sources and in the attendance. Attached is a list of cooperating agencies and individuals, both within and without the Government. The registered attendance—not including many members of Government organizations who "dropped in" for short periods to hear particular papers and discussions—was over 600. There were present eminent geophysicists, hydrologists, hydraulic engineers, civil engineers, agricultural engineers, geographers, biologists, economists, and political scientists, as well as other students and people of affairs who have become concerned with the problem of erosion and flood control, and with conservation in all its aspects.

Supplementary to the conference reported in this volume, the committee organized a third day's program entitled "Young Men's Conference: On Behalf of a Continent." The purpose of this supplementary conference was to interest potential future leaders from all parts of the United States in the problems of soil and water conservation. This supplementary conference, which attracted a substantial audience, presented a program arranged by representatives of 4-H Clubs of America, the National Grange, the Future Farmers of America, the Junior Chamber of Commerce, and the National Youth Administration.

It is hoped that a new impulse has been given to the search for additional scientific data concerning the behavior of waters between the raindrop and the river stages, and to the development of new techniques for application of fundamental principles to beneficial control and use of little waters.

Sincerely,

H. H. BENNETT,
Chief, Soil Conservation Service.

F. A. SILCOX,
Chief, Forest Service.

MORRIS L. COOKE

APPENDIX 3

GENERAL COMMITTEE AND COOPERATING AGENCIES OF THE UPSTREAM ENGINEERING CONFERENCE

GENERAL COMMITTEE

WILLIAM F. DURAND, *Chairman*
Stanford University, Palo Alto, Calif.

Hugh P. Baker, President,
Massachusetts State College,
Amherst, Mass.

H. K. Barrows,
Massachusetts Institute of Technology,
Cambridge, Mass.

Harlan H. Barrows,
University of Chicago,
Chicago, Ill.

Frank D. Bell, Commissioner,
Bureau of Fisheries,
Washington, D. C.

C. P. Berkey, Secretary,
The Geological Society of America,
New York City.

Albert G. Black, Chief,
Bureau of Agricultural Economics,
Washington, D. C.

Isaiah Bowman, President,
Johns Hopkins University,
Baltimore, Md.

Lyman J. Briggs, Director,
National Bureau of Standards,
Washington, D. C.

Bryce C. Browning, Secretary,
Muskingum Conservancy District,
New Philadelphia, Ohio.

L. E. Call, Director,
Agriculture Experiment Station,
Kansas State College of Agriculture,
Manhattan, Kans.

F. R. Carpenter,
Chief of Grazing Division,
Department of the Interior,
Washington, D. C.

H. H. Chapman, President,
Society of American Foresters,
Washington, D. C.

George P. Clements,
Manager, Agriculture Department,
Los Angeles Chamber of Commerce,
Los Angeles, Calif.

George E. Condra, Director,
Department of Conservation and Survey,
University of Nebraska,
Lincoln, Nebr.

J. B. Davidson,
Iowa State College,
Ames, Iowa.

Chester C. Davis, Member of the Board,
Federal Reserve System,
Washington, D. C.

Charles H. Eiffert,
Chief Engineer,
Miami Conservancy District,
Dayton, Ohio.

Charles W. Eliot II,
Executive Officer,
National Resources Board,
Washington, D. C.

Robert Fechner, Director,
Emergency Conservation Work,
Washington, D. C.

S. W. Fletcher, Director of Research,
Pennsylvania State College,
State College, Pa.

Ira N. Gabrielson, Chief,
Bureau of Biological Survey,
Washington, D. C.

Henry S. Graves, Dean,
Yale University, School of Forestry,
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W. R. Gregg, Chief,
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John R. Haynes, President,
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William H. Hobbs, President,
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Frank B. Howe,
Cornell University,
Ithaca, N. Y.

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Thomas H. McDonald, Chief,
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Washington, D. C.

Frank R. McNinch, Chairman,
Federal Power Commission,
Washington, D. C.

J. A. Norris, General Manager,
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Lithgow Osborne,
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New York City.

Paul B. Sears,
University of Oklahoma,
Norman, Okla.

Charles F. Shaw,
University of California,
Berkeley, Calif.

Victor Shelford,
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Harvard University,
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Resettlement Administration,
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North Carolina State College of
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Abel Wolman, Chairman,
Water Resources Committee,
National Resources Committee,
Washington, D. C.

American Association of Engineers.
American Engineering Council.
American Farm Bureau Federation.
American Fisheries Society.
American Forestry Association.
American Geophysical Union.
American Institute of Consulting Engineers.
American Meteorological Society.
American Nature Association.
American Planning and Civic Association.
American Society of Agricultural Engineering.
American Society of Agronomy.
American Society of Municipal Engineers.
American Soil Survey Association.
American Tree Association.
American Wildlife Institute.
The Association of American Geographers.
Association of Land Grant Colleges and Universities.
Association of Southern Agricultural Workers.
Brazos River Conservancy District.
Citizen's Flood Committee of Pittsburgh.
Conference of State Sanitary Engineers.
Eastern States Farmers' Exchange.
Ecological Society of America.
Flood Control Council of Central-Southern New York.
Institute of Irrigation Agriculture of American Farm Bureau Federation.
International Association of Game, Fish and Conservation Commissioners.
International Association of Public Works Officials.
Izaak Walton League of America.
Massachusetts Forestry Association.
Mississippi Valley Association.
Muskingum Watershed Conservancy District.
National Association of Audubon Societies.
National Grange.
National Society of Professional Engineers.
North American Game Breeders Association.
Northeastern Forest Research Council.
Ohio Valley Conservation and Flood Control Congress.
Society of American Foresters.
Society of American Military Engineers.
Southeastern Council.
Southeastern Economic Council.
Southwestern Soil and Water Conservation Conference.
Tri-State Authority (Ohio, Pennsylvania and West Virginia).
U. S. Flood Control Federation.

Department of Agriculture

Agricultural Adjustment Administration.
Bureau of Agricultural Economics.
Bureau of Agricultural Engineering.
Bureau of Biological Survey.
Bureau of Chemistry and Soils.
Bureau of Plant Industry.
Bureau of Public Roads.
Weather Bureau.
Forest Service.
Soil Conservation Service.

Department of Commerce

Bureau of Fisheries.
National Bureau of Standards.

Department of War

Department of the Interior

Bureau of Mines.
Bureau of Reclamation.
Division of Grazing.
General Land Office.
National Park Service.
Office of Indian Affairs.
Geological Survey.

Treasury Department

Public Health Service.

Independent Offices

Emergency Conservation Work.
Farm Credit Administration.
Federal Emergency Administration of Public Works.
Federal Power Commission.
National Academy of Sciences.
National Research Council.
National Resources Committee.
New England Regional Planning Commission.
Pacific Northwest Regional Planning Commission.
Water Resources Committee.
Resettlement Administration.
Tennessee Valley Authority.
Works Progress Administration.

APPENDIX 4

THE SUPPLEMENTARY YOUNG MEN'S CONFERENCE

The organizing committee, realizing that a program of upstream engineering will be one of long duration, believed it to be a mandatory part of its task to interest potential future leaders from all parts of the United States in the problems of soil and water conservation. To this end a third day's conference on the subject "On Behalf of a Continent" was held September 24, 1936. In the making of arrangements for this special conference, the committee wishes to acknowledge the assistance rendered by the deans of the agricultural colleges and engineering schools, the 4–H Clubs of America, the National Grange, the Future Farmers of America, the Junior Chamber of Commerce, the National Youth Administration, and various members of the Seventy-fourth Congress.

THE PROGRAM

Morning session

Presiding officer: Honorable Henry A. Wallace, Secretary of Agriculture.

Address: On Behalf of a Continent, by Honorable Maury Maverick, Representative of the Twentieth Congressional District, Texas.

Reports from the field:

- Conservation and the National Grange in Maryland, by Albert A. Ady, Lecturer, Maryland State Grange, Rockville, Md.
- Conservation and the Four-H Clubs of the Pacific Northwest, by Bernard D. Joy, Associate Agriculturist, Extension Studies and Teaching, Washington, D. C.
- Conservation and the National Youth Administration, by Richard R. Brown, Deputy Executive Director, National Youth Administration, Washington, D. C.
- Conservation and the National Grange in North Carolina, by Harry B. Caldwell, Lecturer, North Carolina State Grange, Greensboro, N. C.
- Conservation Activities of the Extension Service in the Southwest, by O. S. Fisher, Extension Agronomist, Extension Service, Washington, D. C.

Afternoon session

Presiding officer: John W. Studebaker, Commissioner, Office of Education.

Reports from the field (continued):

- Water Conservation and the Extension Service, by W. H. McPheters, Extension Agricultural Engineer, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.
- Conservation and the Future Farmers of America, by William Shaffer, National President, Future Farmers of America, Maurertown, Va.
- Conservation and the American Farm Bureau Federation, by George M. Strayer, Hudson, Iowa.

Motion pictures:

- Forest Fires: Produced by the Forest Service.
- The Plow That Broke the Plains: Produced by the Resettlement Administration.

Addresses:

- How You Can Help:
  - Soil, by H. H. Bennett, Chief, Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C.
  - Forest, by Reed W. Bailey, Director, Inter-Mountain Forest and Range Experiment Station, Ogden, Utah.
  - Upstream Engineering, by Morris L. Cooke, Administrator, Rural Electrification Administration, Washington, D. C.

General discussion.

APPENDIX 5

BIBLIOGRAPHIES AND TECHNICAL JOURNALS FOR PROFESSIONAL READERS

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American Society of Agricultural Engineers: *Agricultural Engineering; Transactions.*

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APPENDIX 6

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A discussion of the use, function, and management of forests.

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An interesting and understandable discussion of the misuse of our natural resources and the need for a national program of conservation.

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Journal of Forestry	The Fertilizer Review
Nature Magazine	Tobacco Grower
Progressive Farmer	Wallace's Farmer

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